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From this it will be seen that only the annual reports, which form parts of the reports of the Secretary of the Interior and are printed as executive documents, are available for gratuitous distribution. While a number of them are furnished the Survey for its exchange list, the bulk of them are supplied directly, through the document-rooms of Congress, to members of the Senate and House. Except, therefore, in those cases in which an extra number is supplied to this office by special resolution, application must be made to members of Congress for the annual report, as for all other executive documents.

The Monographs of the Survey are printed for the Survey alone, and can be distributed by it only through a fair exchange for books needed in its library, or through the sale of those copies over and above the number needed for such exchange. They are not for gratuitous distribution.

The first of these Monographs in numeric order is: THE PRECIOUS METALS OF THE UNITED STATES, BY CLARENCE KING. This will appear during the coming year. The second in numeric order but the first in order of publication is the present work: THE TERTIARY HISTORY OF THE GRAND CAÑON DISTRICT, BY CAPT. C. E. DUTTON.

The price of this volume, with atlas, is $.

Correspondence relating to this and all other Monographs of the Survey, and all remittances, should be addressed to the

DIRECTOR OF THE UNITED STATES GEOLOGICAL SURVEY,
Washington, D. C.

DEPARTMENT OF THE INTERIOR

MONOGRAPHS

OF THE

UNITED STATES GEOLOGICAL SURVEY

VOLUME II

WASHINGTON
GOVERNMENT PRINTING OFFICE
1882

SMITHSONIAN BUTTE — VALLEY OF THE VIRGIN

UNITED STATES GEOLOGICAL SURVEY

J. W. POWELL DIRECTOR

TERTIARY HISTORY

OF THE

GRAND CAÑON DISTRICT

WITH ATLAS

By CLARENCE E. DUTTON

CAPTAIN OF ORDNANCE U. S. A.

WASHINGTON
GOVERNMENT PRINTING OFFICE
1882

PREFACE.

Ever since his memorable journey through the cañons of the Colorado River it has been Major Powell's intention to write a description of the region adjacent to the Grand Cañon and to discuss its geological problems. It is to be regretted that other duties have prevented him. There is no one so well fitted for it, and his right to do so is virtually prescriptive. But the time and opportunity never came to him. When Mr. King assumed the Directorship of the Survey he acceded to Major Powell's desire to have the work in the Grand Cañon district prosecuted, and, in accordance with the wishes of the latter, I was assigned to the immediate charge of it. Much of it was familiar ground. During the seasons spent in the study of the High Plateaus I had found the temptation irresistible to wander far outside of the limits of my prescribed field; and whither should the errant geologist turn his footsteps so eagerly as towards the wonder-land of the south? And so, when the early snows and biting winds of autumn drove us out of the lofty volcanic regions of the north, the remaining weeks of each year were spent in rapid excursions through the milder regions which lie beyond the foot of the great stairway of terraces which leads down from the heights of the Markágunt.

In the summer of 1879 Messrs. Bodfish and Renshawe were employed in making detail maps of more than ordinary accuracy, the former in the Kaibab, the latter in the Uinkaret. Mr. Renshawe completed his field work that season and finished his map in the office the following winter. But Mr. Bodfish's work was much more extensive and difficult, requiring

another field season. Both are entitled to high praise for the skill and ability which they have proven by their results.

In the summer of 1880 I revisited the district for the purpose of making a study of the Uinkaret, and as much of other portions as possible. The geological problems proposed were purely physical. With questions of mere stratigraphy, paleontology, or lithology, I resolved to have no more to do than was essential to an elucidation of the physical questions. The latter are remarkable, and in some respects unique. To present them most clearly and sharply it seemed necessary to disencumber them as much as possible of all subsidiary questions not absolutely essential to their comprehension. Nor did it seem at all satisfactory to gather up disjointed facts merely to swell the aggregate, already vast, of unreduced and uncorrelated observations. It is not enough to know the facts; their meaning is of much greater concern. I have striven, therefore, to group them in their natural order and relations, in order that they may yield testimony as to the causes and processes which have made this region what it is.

I have in many places departed from the severe ascetic style which has become conventional in scientific monographs. Perhaps no apology is called for. Under ordinary circumstances the ascetic discipline is necessary. Give the imagination an inch and it is apt to take an ell, and the fundamental requirement of scientific method—accuracy of statement—is imperiled. But in the Grand Cañon district there is no such danger. The stimulants which are demoralizing elsewhere are necessary here to exalt the mind sufficiently to comprehend the sublimity of the subjects. Their sublimity has in fact been hitherto underrated. Great as is the fame of the Grand Cañon of the Colorado, the half remains to be told.

During the summer of 1880 I was so fortunate as to have the companionship and assistance of Mr. Holmes. His reputation as a field-geologist is already established by his work in connection with Dr. Hayden's Survey. But besides rendering valuable assistance in working out geological details he made many sketches which he has reproduced in the pictures of the text and in the panoramas of the Atlas. To praise such work would be superfluous. But I must call attention to a merit which

may not be so obvious to one who has never seen the region, and this is the wonderful fidelity with which he portrays rock-characters.

The Atlas has been printed by Mr. Julius Bien, of New York, who spared no pains or effort to obtain the best possible results of the lithographic art under the limitations imposed upon him. His success will not be questioned.

C. E. DUTTON.

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THE TERTIARY HISTORY OF THE GRAND CAÑON DISTRICT.

BY CLARENCE E. DUTTON.

ABSTRACT OF THE MONOGRAPH.

This work is chiefly devoted to a description of the methods and results of EROSION upon a grand scale. Since erosion depends for its efficiency principally upon the progressive elevation of a region, and upon its climatal conditions, these collateral subjects are also discussed in their relations to the principal theme. And in general such an erosion influences and is in turn influenced by the whole train of phenomena of which physical geology takes account. I have endeavored to show in what manner and to what extent the most important of these events and groups of events are correlated. In the analysis and synthesis of these processes may be found the materials for reconstructing the history of the evolution of the physical features of the region. This history is indeed but an outline, but in it appear many things which would not readily be discerned without such a comparison.

Chapter I gives a brief and summary account of the geography of the Grand Cañon district and of the distribution both of its topographical and of its principal geological features. It is situated chiefly in northwestern Arizona, with an extension northward into Utah. Its length from northwest to southeast may be taken arbitrarily at about 180 miles, and its width from northeast to southwest at about 125 miles. As no natural boundary can be fixed for its southern portion, its area may be placed

anywhere between 13,000 and 16,000 square miles. The Colorado River of the West runs across the middle of the district in a very tortuous course, averaging west-southwest. Its valley is the Marble Cañon and Grand Cañon.* That part of the district which lies south of the river has been reconnoitered but not thoroughly studied. Its broader geological features are in great part known, but its details remain to be worked out. The portion which lies north of the river has been studied in considerable detail. Upon the northern side six subdivisions may be recognized. Upon the extreme north is a series of terraces carved by erosion out of the Mesozoic and lower Eocene strata, which, covering all the region of the High Plateaus, suddenly terminate in a succession of high cliffs, dropping step by step to lower and lower formations, like a great stairway. At the foot of the stairway is the comparatively smooth platform of the summit Carboniferous, which stretches southward and southeastward into central Arizona for 150 miles or more. The "Terraces" form one subdivision, and are a border country between the High Plateaus on the north and the Grand Cañon district on the south, and may be regarded as the appanage of either district. The main Carboniferous platform north of the river may be subdivided into five distinct plateaus. On the west is the Sheavwits Plateau; next in order towards the east is the Uinkaret; the third is the Kanab Plateau, the fourth is the Kaibab, and the fifth is the Paria Plateau.

The dividing lines between these plateaus are well marked, consisting of great faults or equivalent monoclinal flexures, trending north and south. The westernmost fault bounds the Sheavwits Plateau as well as the district itself, and is named the Grand Wash fault. Beyond it, to the westward, is a region having features very similar to those of the Great Basin of Nevada. Next in order towards the east are the Hurricane and the Toroweap faults. Between the last two is the Uinkaret Plateau. Passing across the Kanab platform we reach the Kaibab, which is hoisted to a greater altitude than the others, with the West Kaibab fault on one side and the East Kaibab

* This name has been repeatedly infringed for purposes of advertisement. The cañon of the Yellowstone has been called "The Grand Cañon." A more flagrant piracy is the naming of the gorge of the Arkansas River in Colorado "The Grand Cañon of Colorado," and many persons who have visited it have been persuaded that they have seen the great chasm. These river valleys are certainly very pleasing and picturesque, but there is no more comparison between them and the mighty chasm of the Colorado River than there is between the Alleghenies or Trosachs and the Himalayas.

monocline on the other. The Paria Plateau is situated at a lower level than the others. East of the latter we come upon the margins of the Mesozoic formations, which wall the Grand Cañon district upon the eastern side and present their broken edges towards it in the Echo Cliffs.

Chapter II gives an account of the Terraces and the strata which they disclose. It also points out the extension of those strata westward and southwestward into the sierra country of southern Nevada, where they assume a littoral character around the Mesozoic mainland, whence their materials were derived. This mainland occupied what is now the site of the Great Basin of Nevada and western Utah. The extensions of the Mesozoic system along the eastern side of the Grand Cañon district are also pointed out. They reach far south into the heart of Arizona and beyond the limits of observation. The edges of the Mesozoic system are found encompassing about two-thirds of the periphery of the district. The remaining part of the circuit now appears to have been the locus of a shore-line. The peculiarities of the cliffs of the terraces are also described and the drainage system is explained.

Chapter III is mainly devoted to a description of the Vermilion Cliffs which bound the Triassic terrace. It is written in effusive style, and is an attempt to portray the magnificent scenery which this colossal wall presents. Its grandeur culminates in the Valley of the Virgen, which is not only of great proportions, but is remarkable and even unrivaled for the beauty and coloring of its rock temples. There is added to this chapter a description of the lowest or Permian terrace.

Chapter IV is devoted to the inference that the Permian, Mesozoic, and Tertiary formations, now ending cliff-wise in the terraces, once extended over the entire expanse of the Carboniferous platform of the Grand Cañon district. During Tertiary time they were denuded, and the total thickness of strata thus swept away, though varying somewhat and perhaps notably in different places, averaged probably about 9,000 feet. The evidences upon which this conclusion rests are discussed at some length and carefully criticised, and the conclusion is believed to be well sustained by the evidence.

The argument for the conclusions reached is mainly derived from the

convergence of three groups of facts upon a common inference: 1, the stratification; 2, the displacements; 3, the lateral drainage system In some respects the argument is novel, and in all respects its various elements are pushed to a much greater extreme than there is precedent for in the works of physical geologists; but this is held to be justified by the wonderful clearness and simplicity of the observed facts, which are quite unparalleled in any other portion of the world.

In Chapter V the descriptive treatment is resumed for the purpose of developing additional facts bearing upon the broader problems of the evolution of the physical features of the region, upon the sequence of events and the epochs of their occurrence. With this purpose the reader is conducted in an imaginary journey from the base of the Vermilion Cliffs across the Carboniferous platform to the Toroweap Valley and to the Grand Cañon. The Toroweap is a broad lateral valley upon the eastern flank of the Uinkaret, cut down only two-fifths of the depth of the great chasm. It enters the Grand Cañon, opening upon the great esplanade between its upper walls. The cañon here is at its narrowest. It consists of an inner and an outer chasm. The upper or outer one is about five miles in width, with a row of palisades on either side 2,000 feet high, and with a flat broad esplanade between. In the floor of this esplanade is sunk the inner gorge 3,000 feet deeper, and from 3,000 to 3,500 feet wide. The total depth of the cañon here is about 5,000 feet. After a hurried mention of the principal features of this stupendous scenery the reader is invited to take his seat upon "Vulcan's Throne," a basaltic cinder cone 600 feet high, planted upon the brink of the inner gorge just where the axis of the Toroweap intersects that of the cañon. Apart from the merely scenic effects it would be hard to find anywhere in the world a spot presenting so much material for the contemplation of the geologist. The Toroweap fault is clearly revealed in the opposite cañon wall and its recency disclosed. It is also shown that the vast inner gorge has been very recently excavated, and that it was swiftly cut. Its age is regarded as being mostly Post-Tertiary. The outer chasm is shown to be much older, and it is very probable that the river, after cutting down to the level of the esplanade, remained for a time stationary, and ceased temporarily to deepen its channel. The age of the

Toroweap Valley is also inferred. It appears to be the channel of an ancient river long since dried up. It is the type of a number of ancient tributaries of the Colorado, which collectively throw light upon its Tertiary history. Many other facts are recited, for which the reader is referred to the chapter itself.

Chapter VI describes the Uinkaret Plateau. Since the Uinkaret and Sheavwits are very similar to each other in their geological features and relations, the former alone is discussed as the type of the two. Three subjects receive attention: 1st, the volcanism; 2d, the Hurricane fault; 3d, the remnants of Permian strata. The lavas are all basaltic and very homogenous in character. They are of two ages, the earlier being referred approximately to the early Pliocene or possibly late Miocene, the later to very recent time, some being probably but a very few centuries old. A long interval of time separated the two eruptive periods.

The Hurricane fault is also described at length, and its comparative recency pointed out. The Permian remnants here are important as relics of an ancient topography preserved by the protection of the more ancient basalts, and as indicating the former extension of that formation over the entire district. The lavas, the fault, and the Permian all throw light on the sequence, epochs and relations, of those events which make up the history of the region. Each by itself would be of little moment. But by grouping them together in their proper relations and viewing them as a whole they reveal much. It now begins to appear that the chasm had its origin in the latter part of Tertiary time, that the faults are no older, and that they, as well as the volcanism of the region, are associated with periods of upheaval, and that these periods are reflected in the various stages of the excavation of the chasm. The great denudation also finds further support in the facts here presented.

Chapter VII resumes the narrative treatment, and the reader is conducted on an imaginary journey from the base of the Vermilion Cliffs to the Kaibab Plateau and upon its summit to the brink of the chasm. Along the route such facts as are of special geological interest are noted and remarked upon, and the attempt is made to convey a mental picture of the region traversed. I have taken the liberty in this chapter of attacking the

reader through his imagination, and, while trying to amuse his fancy with pictures of travel, have sought to thrust upon him unawares certain facts which I regard as of importance, but which would have been overlooked or forgotten if treated in the ordinary fashion of formal monographs.

Chapter VIII is a description of the scenery of the Kaibab division of the Grand Cañon from Point Sublime, one of the promontories which project far out into the heart of the chasm. It is one of many panoramas all of which are sublime in the highest degree. The scenery of the Kaibab division is very much grander than in other divisions of the chasm, and even the least imposing portions of the cañon are in their general effects upon the sensibilities as impressive as any scenery to be found in the world.

Chapter IX describes the larger and more striking amphitheaters along the Kaibab front. It also contains an account of the great unconformity disclosed at the head of the Grand Cañon. For a distance of twelve miles may be seen in the depths of the chasm the contact of the Carboniferous with a vast mass of Silurian and possibly some Devonian strata. The latter are inclined at a varying angle of dip, and at the plane of contact are beveled off to a smooth surface, which at the beginning of Carboniferous time was no doubt sensibly horizontal.

Chapter X explains the structural features and the somewhat intricate drainage system of the surface of the Kaibab Plateau, and discusses their relations to the evolution of the chasm and of the plateau itself. The displacements occurring on either side of the plateau, are described in some detail. The drainage system, consisting of a minutely ramified plexus of ravines, is accorded a very recent origin, with the exception of one remarkable valley spoken of in Chapter VII. This valley is shown to be probably an ancient river channel, tributary to the Colorado, but dried up at a very early stage of the excavation of the present cañon.

Chapter XI treats in a very brief and cursory manner of the Paria Plateau and of the Marble Cañon platform.

Chapter XII generalizes, interprets, and draws conclusions from the facts set forth in all of the preceding chapters, and groups them into a history of the evolution of the region. Prior to Carboniferous time large masses of Silurian strata and some Devonian beds were deposited. The

country was then upheaved, enormously eroded and again submerged. Upon the denuded surface the Carboniferous was deposited unconformably, and deposition continued without notable interruption until the close of the Mesozoic. In that long succession of ages from 12,000 to 16,000 feet of strata accumulated over the entire Plateau Province. The beds are remarkable for their homogeneity and constancy of character over vast areas, though the different formations vary greatly in lithological character; that is to say, homogeneity in horizontal range, with great heterogeneity in vertical range. The Carboniferous system may have accumulated in waters of moderate depth, but the Mesozoic beds are all shallow-water deposits The surface of deposition remained throughout Permian and Mesozoic time very near sea level, which is equivalent to saying that the beds sank as rapidly as they accumulated. Near the close of the Cretaceous signs of the coming revolution make their appearance. The waters became brackish, indicating a restricted access of the ocean. At the close of the Cretaceous important disturbances took place, and portions of the province were uplifted and denuded. These were again submerged, but the new conditions differed from the old, for the new deposits (Eocene) laid down unconformably upon the Cretaceous and Jurassic are of fresh-water origin, indicating that a great lake was formed. The extent of this lake corresponds very nearly with that of the Southern Plateau Province itself, but not exactly. Near the middle Eocene began that slow action which has gradually elevated the western portion of the continent, and which has prevailed until a recent epoch. It does not appear to have progressed at a constant rate, but rather by maxima and minima, or still more probably through alternating periods of activity and repose.

The Tertiary history of the region is a great chapter of erosion. Many thousands of feet of strata have been swept away. The thickness removed from some large areas amounts to about 10,000 feet, while from others a much less thickness has been denuded. In the Grand Cañon district we find the largest area of maximum erosion. Much the greater part of this denudation was probably accomplished by the close of the Miocene.

The Colorado River appears to have originated in very early Tertiary time as the outlet of the great Eocene lake, and has persisted in its course

ever since. It has been the main track along which the waste of the province has been carried to the Pacific. At its beginning its bed lay in Eocene strata, and as the land rose it cut down its channel by corrasion, severing in succession all the beds of the Mesozoic and Carboniferous systems That portion of it which constitutes the Grand and Marble Cañons has cut through 10,000 to 16,000 feet of beds, reaching a maximum amount in the Kaibab. The present Grand Cañon represents only the corrasion through the Carboniferous and into the Archæan. The older corrasion of superior beds becomes manifest only when we restore in imagination the Mesozoic strata which have been denuded from the vicinity of the chasm. The present Grand Cañon therefore is the work of late Tertiary and Quaternary time. Although we cannot fix with precision the exact epoch at which the river first penetrated the Carboniferous beds, we may in roughly approximate language place that epoch near the beginning of the Pliocene or close of the Miocene. These terms, however, are used with considerable latitude. Some critical events in the subsequent development of the chasm are pointed out and the evidences cited.

Chapters XIII and XIV deal with the mechanical laws, forces, and methods of action by which the cañon has been corraded and eroded, and explain how those abnormal architectural forms so abundantly displayed in the chasm and in the region roundabout have been generated.

CHAPTER I.

GENERAL DESCRIPTION.

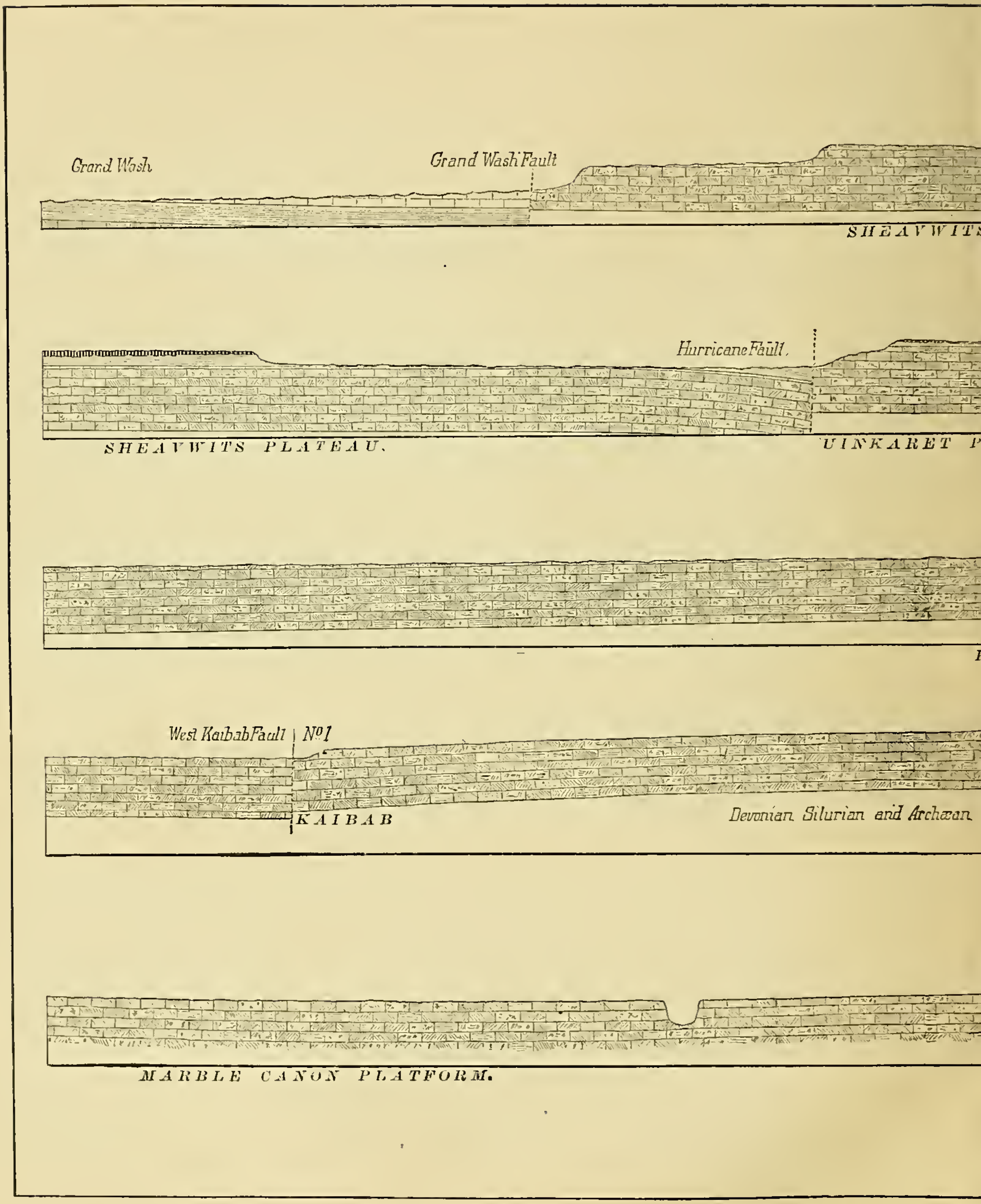
Subdivisions of the Plateau Province.—The boundaries of the Grand Cañon district.—The western boundary at the Grand Wash.— Its northern border along the terraces.—The southern and southwestern margin at the Aubrey Cliffs.—The Sheavwits Plateau.—The Uinkaret.—The Kanab Plateau.—The Kaibab.—The Paria Plateau and Marble Cañon platform.—The Kaiparowits.—The Colorado Plateau south of the river.—The San Francisco Mountains.—The terraces forming the border region descending from the High Plateaus to the Grand Cañon platform.—The Eocene and Mesozoic strata of these terraces and their terminal cliffs.—The Vermilion Cliffs.—The Permian terrace.—Eastern boundary of the district along the Echo Cliffs and terminations of the Mesozoic strata of the central mesas of the province.—The displacements.—General inclination of the great Carboniferous platform of the district.—The systematic character of the faults.—The Grand Wash fault.—Hurricane fault.—Toroweap fault.—Southern termination of the Sevier fault.—Western and Eastern Kaibab displacements.—Echo Cliff monocline.—General arrangement of the faults.—The drainage system of the region.—Course of the Colorado through the district in the Marble and Grand Cañons.—Divisions of the Grand Cañon.—Its length and dimensions.—Its general characteristics in the several plateaus which it traverses.—The rivers of the terraces.—The Virgen.—Kanab River.—Paria River.—Paucity of tributaries to the Grand Cañon.

In numerous works upon western geology those features which give the Plateau Province its distinct character have been the subjects of extended description; and its boundaries, so far as they have been discovered, have been indicated. They are gradually becoming familiar to students of geology, and no general account of them is deemed necessary here. The province is capable of subdivision into component districts, each of which, while preserving the plateau features, has peculiarities of its own. Three of these have already been the subjects of special monographs;* viz, the Uinta Mountains, the Henry Mountains and the High Plateaus. The interest in this remarkable province no doubt culminates in that portion of it which drains into the Grand Cañon of the Colorado. This is the westernmost—perhaps we may say the southwesternmost—portion of the Plateau

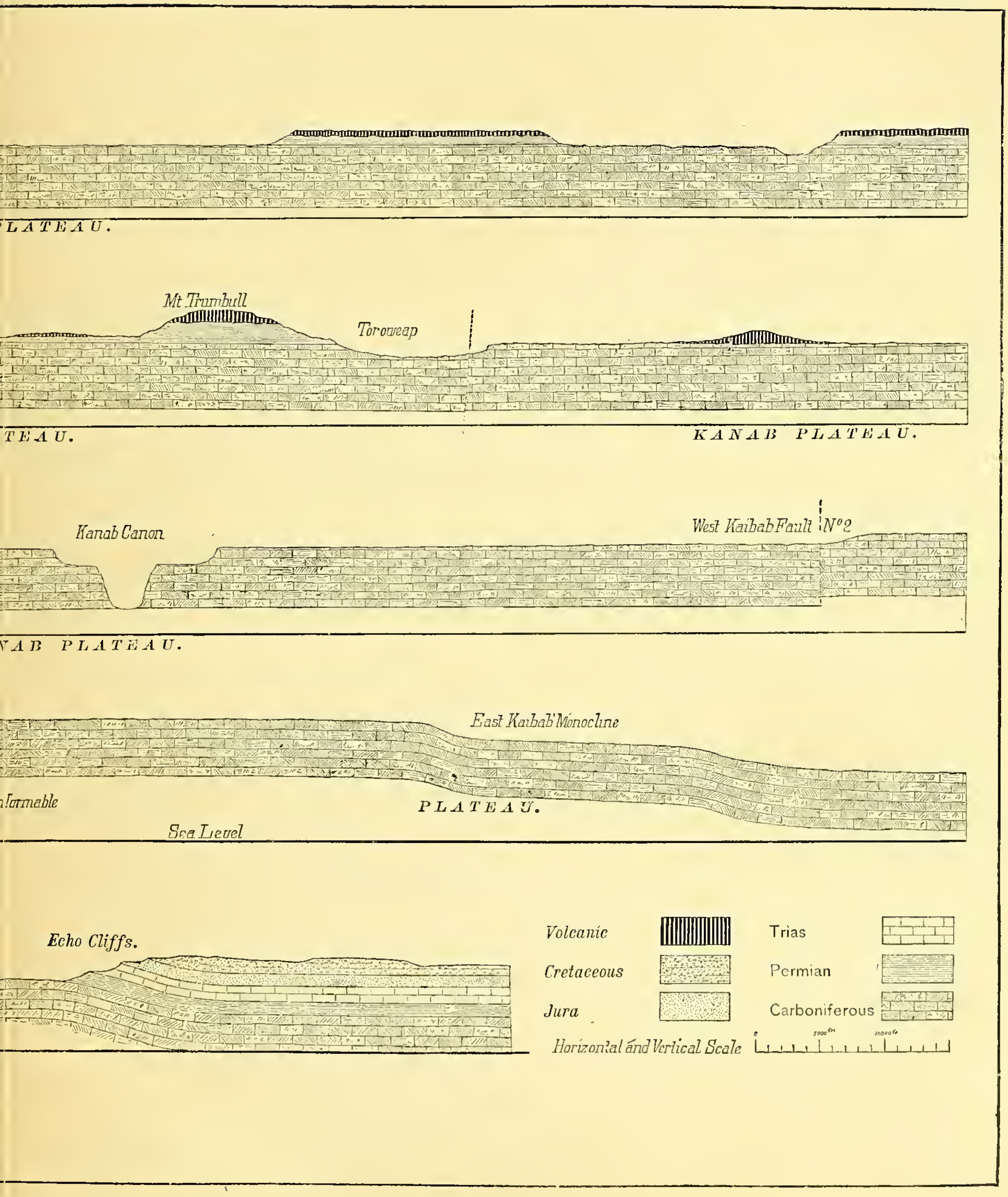
* These three monographs are the published Reports of the Geographical and Geological Survey of the Rocky Mountain Region, J. W. Powell in charge. The first of them, "The Geology of the Uinta Mountains," is the work of J. W. Powell; the second, "The Henry Mountains," is by G. K. Gilbert; the third, "Geology of the High Plateaus of Utah," is by C. E. Dutton. They were all originally contemplated as subsidiary to a more general treatise upon the geology of the Plateau country at large.

country. North of it rise the High Plateaus of Utah; to the eastward are the central regions of the Plateau Province; and to the southward and westward is a sierra country, which remains to be well explored before its distinctive features can be described. Upon the west the district terminates abruptly upon the brink of a great wall, where the surface of the country drops at once from an elevation of more than 6,000 feet to levels ranging from 1,300 to 3,000 feet above the sea. Every traveler in the far west has noted the desolate character of the country through which the Central Pacific Railway in Nevada is laid; and every feature of that desolation is intensified in degree, though identical in kind, in the nameless and formidable desert which lies west of the Grand Cañon district.

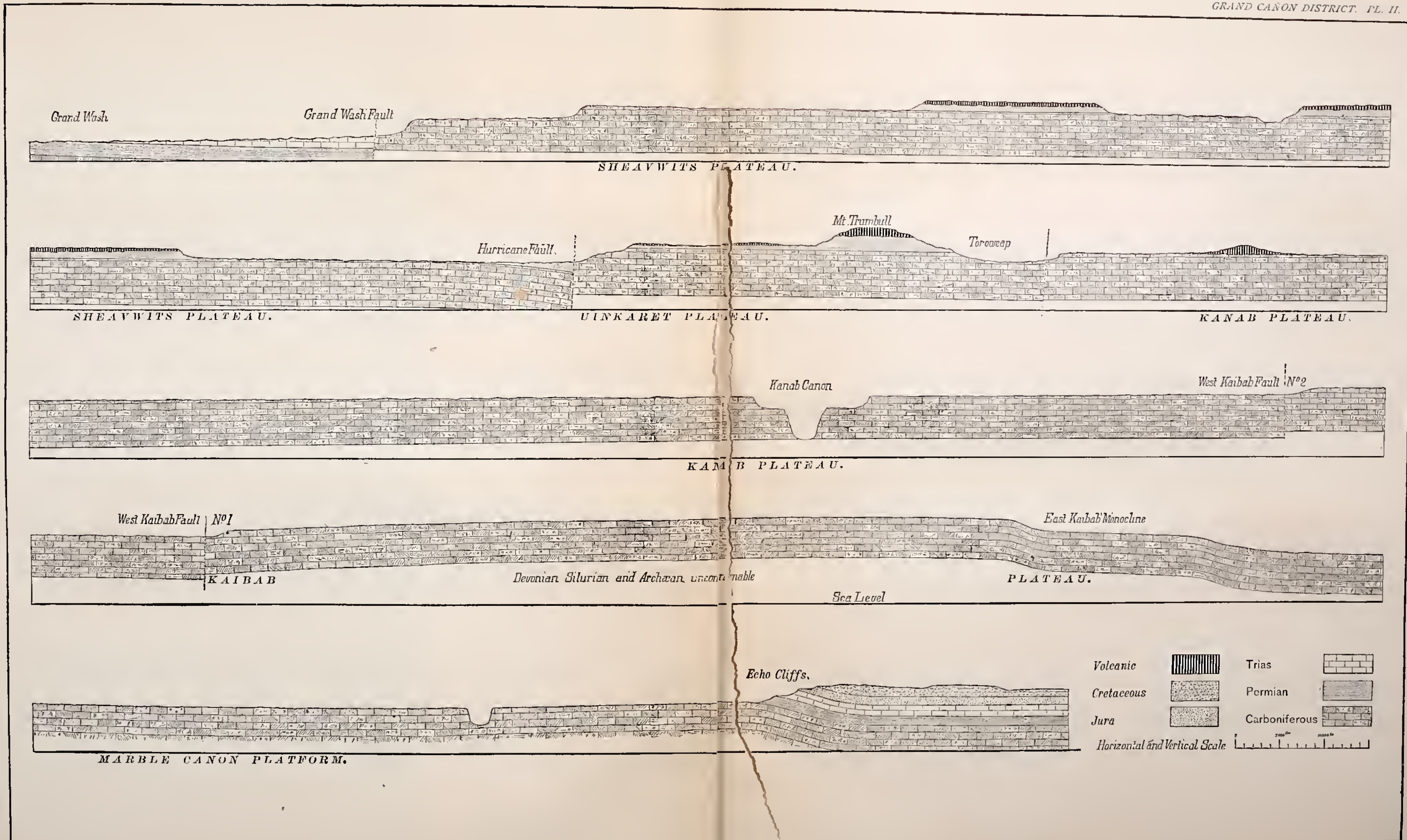
It is not altogether clear where the boundaries of the district should be drawn, nor what it should be made to include. So far as the western boundary is concerned there is no room for debate. It lies along the great escarpment which overlooks the rugged sierras and desert. From the very foot of that wall the calm repose of the strata with horizontal surfaces changes at once to the turmoil of flexed beds and jagged mountain crests. It is a portion of that trenchant boundary line which separates the topography of the Plateaus from that of the Great Basin and of the region south of the Great Basin so sharply that we may almost hurl a stone from one region to the other. But it is not so obvious where the eastern limit should be drawn. The Grand Cañon receives from the north the drainage of four distinct plateaus: the Sheavwits, Uinkaret, Kanab, and Kaibab. East of these lies a fifth, the Paria Plateau, which drains into the Marble Cañon, and the Marble Cañon is but the prelude to the Grand Cañon. Structurally the Paria Plateau is quite similar to the others; it has shared in their history and evolution, and its topography is substantially the same in many respects, though not in all. It differs from the rest mainly in lying at a lower level and in the fact that the greater portion of its surface is covered with Triassic rocks, while the others present an almost unbroken expanse of Carboniferous beds. These two facts run off into consequences which are very interesting in themselves, but which often mar the simplicity which is presented to the mind in the study of the Grand Cañon district, as limited to the other four plateaus. Hence it will be convenient to play fast and loose



SECTION FROM EAST TO WEST



ROSS THE GRAND CAÑON DISTRICT.



SECTION FROM EAST TO WEST ACROSS THE GRAND CAÑON DISTRICT.

with the Paria subdivision, invoking its presence whenever it can be utilized and dismissing it from the discussion whenever it is *de trop*.

If we were content to discuss merely the existing topography, the northern boundary would soon be chosen at the base of the Vermilion Cliffs, where the splendid succession of terraces ends and the broad expanse of the desert begins. But the geologist, looking beyond the visible present into the past, seeks for history and the process of evolution. The history of the Grand Cañon district is a remarkable one, and its few remaining records are in great part disclosed to us in the terraces which lead up to the High Plateaus. These terraces may be regarded as the appanage of either district—as the common ground where the threads of their respective histories are interwoven. Neither district can be comprehended without some knowledge of the terraces, and since they have been lightly touched upon in the monograph of the High Plateaus, it is deemed necessary to give a fuller account of them here.

The southern boundary of the district is a continuation of the western boundary. The grand escarpment which overlooks the sierra country to the west stretches southward across the Colorado, preserving identical features as far as it has been thoroughly studied; that is, as far as thirty or forty miles south of the river. We do not know as yet whether this continuity of character and relations in the terminal escarpment persists far beyond that point, but, from the superficial knowledge we possess, it may be inferred that it does. As far as we know, and we have accounts covering the entire southern border, the great mural termination of the Carboniferous platform which constitutes the surface of the district slowly changes its trend south of the river, and at length follows an east-southeasterly course through eastern Arizona. There, as at the Grand Wash, the surface of the country descends at once from the horizontal platform into a lower country, apparently identical in its topographic and geologic features with the Great Basin and with the terrible desert along the lower courses of the Colorado. But whether the passage is across a great fault, as it is at the western side of the district, still remains to be investigated.

The four plateaus thus far named, all lie upon the northern side of the Colorado. They are for the most part divided by distinct lines and only

here and there shade into each other. The westernmost is the Sheavwits Plateau. Its western boundary is a gigantic escarpment, overlooking the Grand Wash, a broad and deep valley descending from the north to the Colorado, and reaching the river at the mouth of the Grand Cañon. This "wash" carries the drainage from a considerable area lying to the northwestward, and also from the western wall of the plateau. No river runs there, but only occasional deluges of mud, whenever the storms from the southeast are flung against the lofty battlements and break in torrents of winter rain. The plateau wall had its origin in a great fault along the course of which the country east of it has been hoisted several thousand feet above the country on the west. The shear of this fault diminishes to the northward and appears to vanish about forty miles north of the Colorado, but its details remain to be studied. From the crest of the escarpment the plateau has a very gentle slope towards the east and northeast, for a distance of about 30 miles. Its surface is diversified by some volcanic masses, and by a few large Permian outliers, capped by basaltic sheets. One considerable mass of basalt forms Mount Dellenbaugh, in the southern part of the plateau, and around its base spreads out a large basaltic field. The eastern limit of the Sheavwits is at the foot of the Hurricane Ledge, one of the most striking of the strong geological and topographical features of the region. The profile of the country, which has gradually declined from the western verge of the Sheavwits, suddenly leaps upward 1,600 to 1,800 feet. Here begins the UINKARET PLATEAU.

It is the narrowest of the four, but is strongly marked in its features. Its southern portion has been the scene of basaltic eruptions of considerable magnitude, though far inferior in extent and mass to those of other districts around the borders of the Plateau Province. But they are very interesting in consequence of their connection with other features of the plateau and with their history. The cones and *coulées* are in an excellent state of preservation, and some of them have a singular freshness and an aspect of great recency. The positions of many of the basaltic masses amid the stupendous scenery of the great chasm and its tributary valleys, are highly impressive and suggestive. On this plateau also the basalt has preserved the Permian beds in several localities, and the manner of

this preservation yields, when carefully studied, much information concerning the progress of the events which have made this region what it is. The western boundary of the Uinkaret is the Hurricane Ledge, which preserves its features throughout the entire length of the plateau and continues far beyond it with increasing emphasis to the northward. The eastern boundary is not so persistent. It consists in part of the Toroweap fault, which is a strong feature in the vicinity of the Grand Cañon, but diminishes northward and finally dies out about 18 miles from the chasm. North of this there is no structural and no resulting topographical feature separating the Uinkaret from the next subdivision.

The KANAB PLATEAU is the broadest of the four, and the least pronounced in its features. It is a simple monotonous expanse, without a salient point to fix the attention, save one. This is a magnificent side cañon, cutting through its central portion and opening into the heart of the Grand Cañon. It is as instructive as it is magnificent.

Next in order, east of the Kanab Plateau, rises the KAIBAB. It is typical in its form, being nearly flat upon its summit and terminating in lofty battlements upon its eastern and western sides. It is much higher than the other three plateaus and has an elevation of 7,500 to 9,300 feet. Its broad surface is clothed with magnificent forest, opening in grassy parks, which during the summer are gay with flowers of rare beauty and luxuriance. It is a paradise to the explorer, who, weary of the desert, wanders with delight among its giant pines and spruces, and through its verdant but streamless valleys. This plateau is an uplift between two great displacements, throwing in opposite directions. Towards the north these converge, and near the little village of Paria, at the base of the Vermilion Cliffs, the western fault merges into the eastern and the plateau ends there in a cusp. The western fault in its southern portion splits into three, which die out upon the brink of the Grand Cañon or hard by it. The eastern displacement is a monocline of huge proportions, and about midlength it divides into two parallel monoclines, which die out upon the southern side of the Colorado. The total length of the Kaibab from the Vermilion Cliffs to the Grand Cañon is about 90 miles, and its width at a maximum about 35 miles.

East of this plateau the surface drops quickly across the great monocline, nearly 4,000 feet, upon the region draining into the Marble Cañon. This region is divisible into two parts, a northern and a southern. The former, named the PARIA PLATEAU, is a terrace of Triassic strata, scored with a labyrinth of cañons, but otherwise featureless so far as its summit is concerned. It terminates abruptly towards the south by a line of cliffs, describing a semicircle convex southward. They are an extension of the Vermilion Cliffs, and their position, projecting far in advance of the main line, is very instructive when viewed in connection with the grand erosion of this part of the Plateau Province. Their profiles drop upon a lower platform which extends far to the southward, hot, dreary, and barren, to an extreme degree. Diagonally across this lower platform lies the course of the Marble Cañon, which in depth and grandeur is surpassed only by the Grand Cañon.

Still eastward, and more to the northward, is another large plateau, the KAIPAROWITS, nearly equal to the Kaibab, both in area and altitude. It reaches out from the southern cape of the Aquarius, extending to the Glen Cañon of the Colorado. It is composed of lower and middle Cretaceous beds, and if the chasm cut by the river were filled up again the plateau would spread out on the southern side into an indefinite expanse of Cretaceous strata, which form the great mesas of that region. Its surface is scored with a plexus of cañons which are interesting as the relics of an erosion which is believed to have occurred in late Meocene or early Pliocene time.

Thus far the description has been confined to regions lying north of the Colorado. Upon the southern side is an expanse of plateau land equally extensive. Those well marked boundaries which subdivide the district north of the Grand Cañon into individual plateaus do not appear upon the southern side, or else appear in such changed relations that they cannot serve the same purpose. The country which drains from the south into the cañon really has no subdivisions, but is a single indivisible expanse to which the name of COLORADO PLATEAU has been given. Its strata are very nearly horizontal, and with the exception of Cataract Cañon and some of its tributaries it is not deeply scored. Low mesas gently rolling and

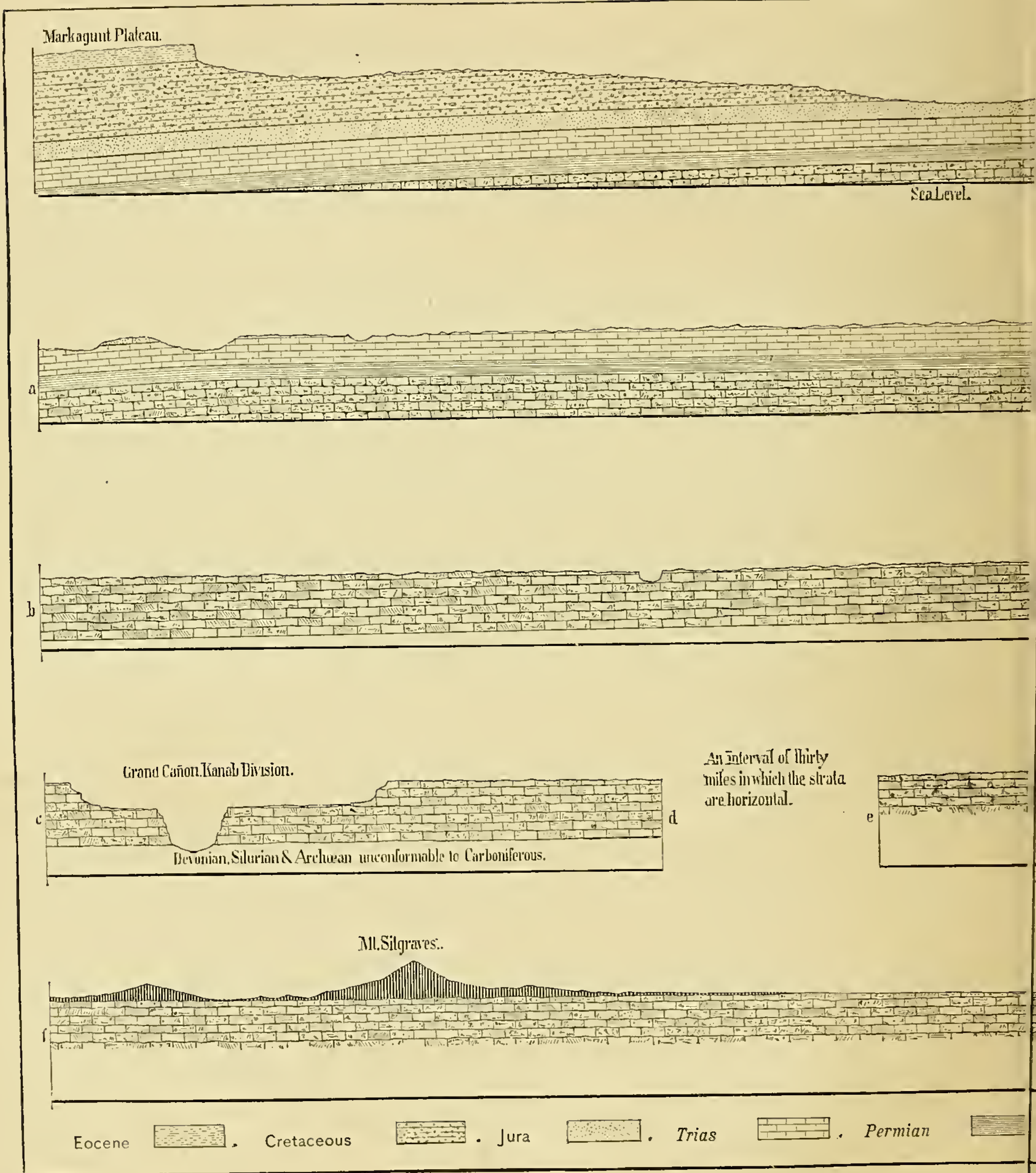
usually clad with an ample growth of pine, piñon and cedar; broad and shallow valleys, yellow with sand or gray with sage, repeat themselves over the entire area. The altitude is greater than the plateaus north of the chasm except the Kaibab, being on an average not far from 7,000 to 7,500 feet. From such commanding points as give an overlook of this region one lonely butte is always visible and even conspicuous by reason of its isolation. It stands about twenty miles south of the Kaibab division of the Grand Cañon and is named the Red Butte. It consists of Permian strata lying like a cameo upon the general platform of Carboniferous beds. The nearest remnant of similar beds is many miles away. The butte owes its preservation to a mantle of basalt which came to the surface near the center of its summit. It is an important factor in the evidence upon which rest the deductions concerning the great erosion of this country.

Fifty or sixty miles south of the river rise the San Francisco Mountains. They are all volcanoes, and four of them are of large dimensions. The largest, San Francisco Mountain, nearly 13,000 feet high, might be classed among the largest volcanic piles of the west. Around these four masses are scattered many cones, and the lavas which emanated from them have sheeted over a large area. The foundation upon which they are planted is still the same platform of level Carboniferous strata which stretches calmly and evenly from the base of the Vermilion Cliffs for more than one hundred and fifty miles southward, patched over here and there with the lingering remnants of lower Permian strata and isolated sheets of basalt. South of the San Francisco Mountains the level Carboniferous platform extends for twenty or thirty miles, and at last ends abruptly in the Aubrey Cliffs, which face southward and southwestward, overlooking the sierra country of central Arizona.

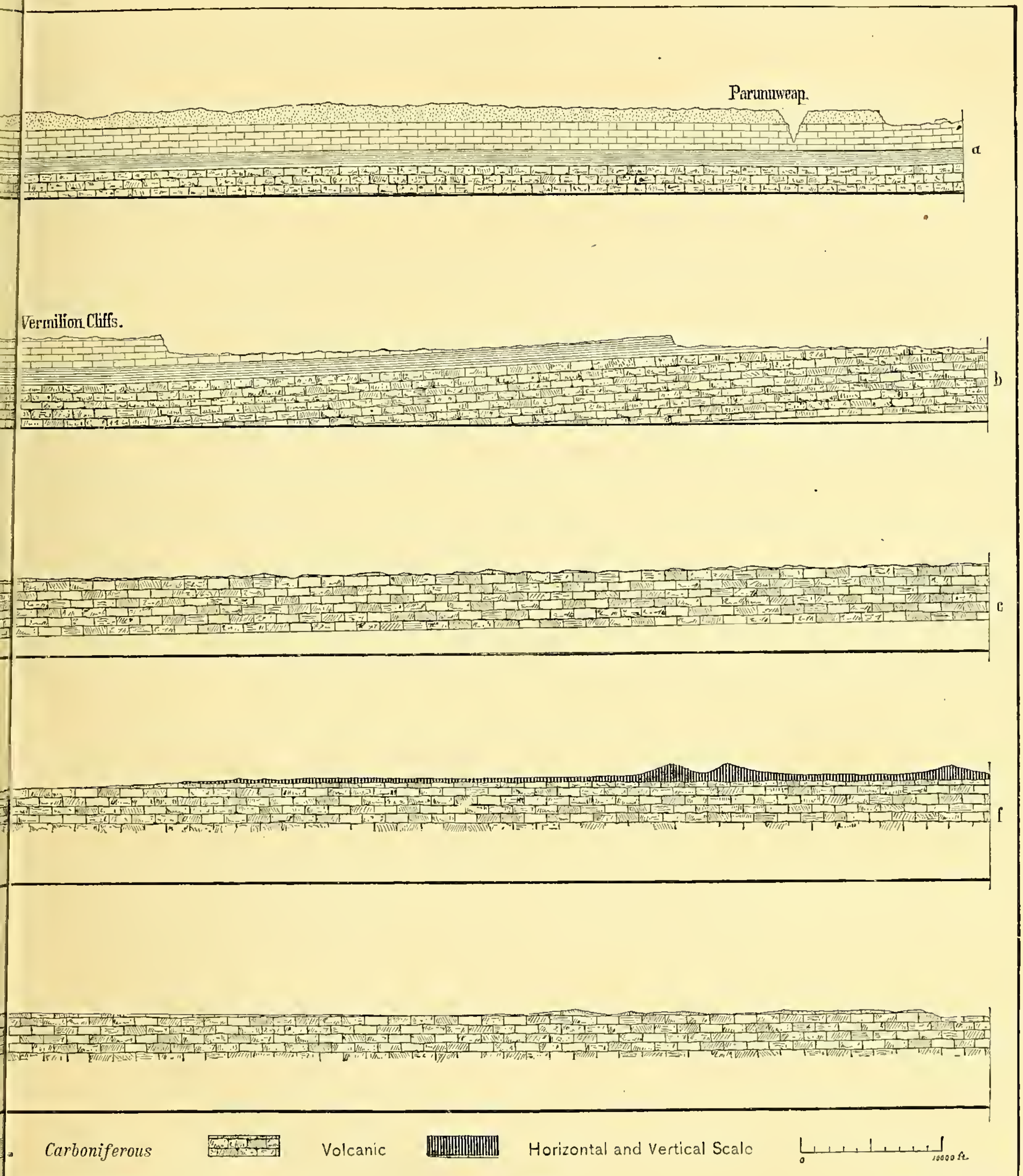
Recapitulating now in regular order from west to east the several plateaus which lie immediately north of the Grand Cañon, we note: 1. The Sheavwits; 2. The Uinkaret; 3. The Kanab; 4. The Kaibab. East of these, and draining into the Marble Cañon from the north, is the Paria Plateau. South of the Grand Cañon is the great expanse of the Colorado Plateau. The limits of the district must also be extended to include the

belt of terraces which descend from the High Plateaus on the north through a succession of steps to the four plateaus first mentioned.

If we proceed southward from the district of the High Plateaus of Utah, we shall gradually descend from an altitude of more than 10,000 feet to one of less than 5,000 feet. The country thus traversed is terraced off in a succession of steps, each terrace being terminated by a sinuous line of cliffs or abrupt slopes. Each cliff is the limiting border of a great series of strata, no member of which is encountered again for an indefinite distance to the southward. As we descend each cliff we find ourselves at its base upon the summit of a lower series. From the crest of each escarpment the stratum on which we stand constitutes the surface of the country to the northward as far as the foot of the next terrace above us, and it has a very gentle and hardly perceptible dip in that direction. The whole series in fact has a slight dip to the northward. The uppermost series is the Eocene, which forms the summits of the southern members of the High Plateaus. Only the lower members of the Eocene are there present, and these appear by their fossils to be certainly equivalent in age to those beds in the Green River Basin and upon the slopes of the Uinta Mountains to which Powell gave the local name of Bitter Creek beds, and which King called Vermilion Creek. At the southern boundaries of the Markágunt and Paunságunt plateaus the vertical edges of these strata have received the name of the Pink Cliffs. They are exceedingly picturesque and beautiful on account of their marvellous sculpture and delicate pale red color. Beneath them and extending farther southward is the great Cretaceous series, which in these parts does not give rise to cliffs, though farther east in the Upper Paria amphitheater it presents palisades of grand proportions and magnificent aspect. Here its strata are beveled off on their edges in such manner, that while their dip is gently towards the north the planes of denudation incline strongly towards the south, and the edges form long slopes of disintegrated shale with low crumbling ledges of sandstone. From beneath the Cretaceous project southward two divisions of the Jurassic, the upper consisting of red shaly beds which disintegrate easily and do not ordinarily form cliffs; and the lower, a massive sandstone, a thousand feet thick and of commanding aspect. It is very light gray—almost white—

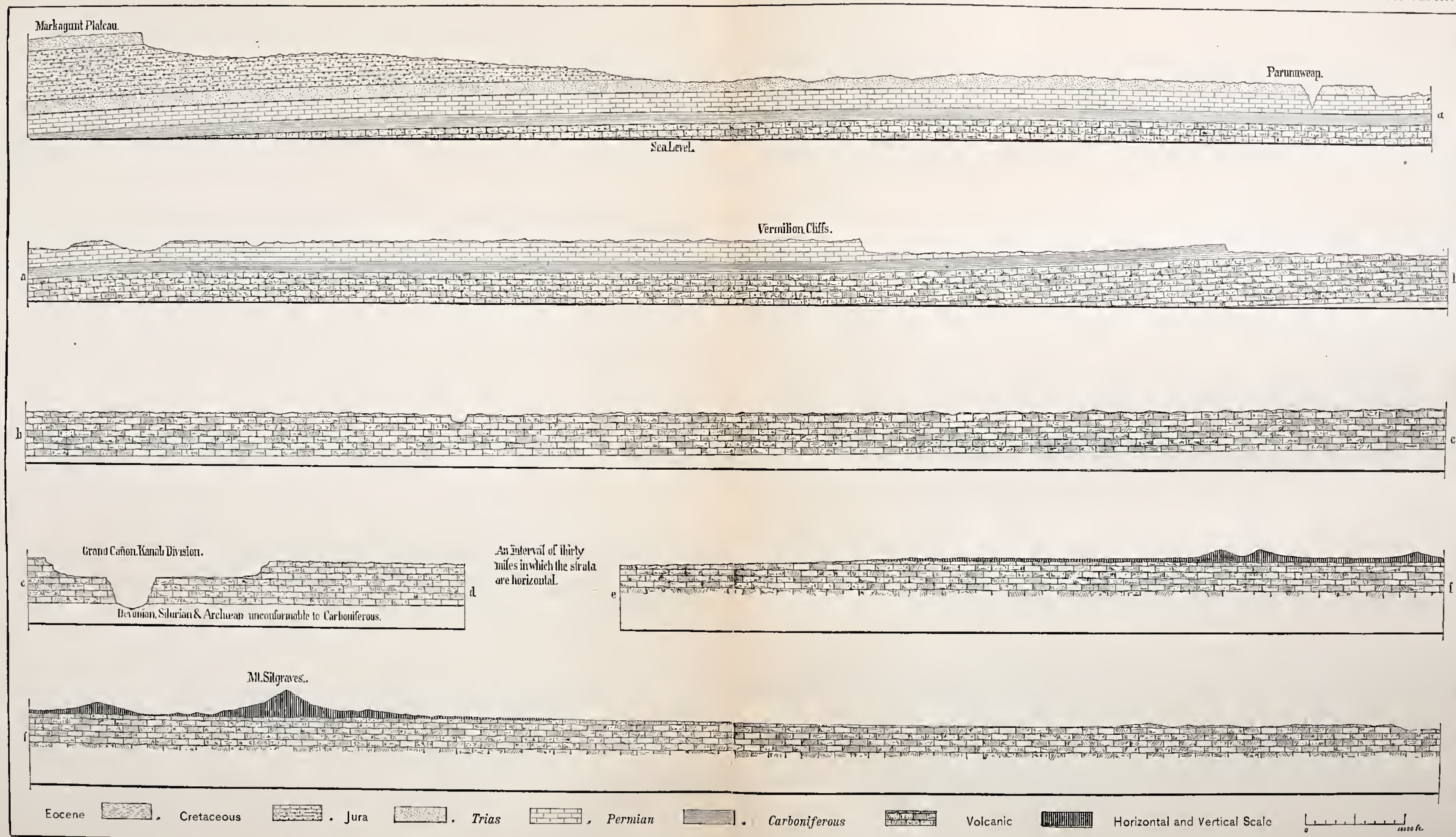


SECTION FROM NORTH TO SOUTH



S. H. Bodfish, Del.

ROSS THE GRAND CAÑON DISTRICT.



S.H.Bodfish. Del.

SECTION FROM NORTH TO SOUTH ACROSS THE GRAND CAÑON DISTRICT.

and cross-bedded from top to bottom in a most intricate and profuse manner. The weathering has given to these rocks a filagree tracery as beautiful as frostwork. The Jurassic sandstone terminates in grand cliffs of singular boldness and great simplicity of form. Next below reaches out the Triassic series, ending in that wonderful escarpment which Powell has described under the name of Vermilion Cliffs. The terminal wall is from 1,000 to 2,000 feet in height, and presents a great number of layers of sandstone and sandy shales with gypsiferous partings. These are very evenly stratified, and the cliffs which are carved out of them present many ledges and slopes which have a very ornate and architectural effect. The color is throughout a bright rich red, which at sunset takes a strong vermilion hue and fully justifies the name given by Powell. Altogether it is the greatest cliff-forming series of the Plateau country. The Vermilion Cliffs stretch from the southwestern border of the Markágunt in a great curve as far as the Paria Valley, a distance of more than a hundred miles in which sinuosities are not computed.

There is yet another terrace. Beneath the Trias the Permian is seen, reaching still further southward. It is everywhere capped with a light brown, coarse sandstone, here and there passing into a conglomerate, to which Powell gave the local name of Shinarump conglomerate. Mr. Walcott, for reasons which will hereafter be presented, has placed this particular stratum provisionally at the base of the Trias, and while I admit the validity of his reasons, it makes some awkward difficulties of discussion; for in all its topographical relations it is associated with the Permian. The true Permian lies beneath it, presenting in its upper members those densely colored shales—chocolate, dark red, brown, purple, slate, and lavender, in numberless tones and shades. Lower down, dull Indian red, and still lower, white or pale grey bands appear. Wonderful indeed is the coloring of the Permian, yet not more so than the sculpture. The series forms cliffs of rather small or moderate altitude, ranging from 400 to 1,000 feet in height, and sometimes interrupted through notable intervals where they are beveled off. Having passed the Permian, we find ourselves upon the immense platform of the Carboniferous, which covers the entire expanse of country as

far as the Aubrey Cliffs, 150 miles to the southward, and has a width of 100 miles.

The region occupied by the terraces has a width from north to south of about 30 to 40 miles, and a length from west to east of nearly 100 miles. The trend of the cliffs is in detail very irregular, making long detours and throwing out great southward projections. Still there is much of system in their arrangement, and a rude kind of parallelism in the trends of their escarpments. In a general way their course is from west to east, reaching from the Hurricane Ledge to the valley of the Paria. It is desirable to follow the course of these cliffs beyond the Paria and note the manner in which they terminate the strata along the eastern side of the district.

At the Paria River the limiting edges of the Mesozoic strata suddenly change their trend and strike off to the southward, or rather in courses a little east of south. For more than 140 miles they form the eastern boundary of the Grand and Marble Cañon area. Their topographical features, however, are very different from those presented upon the southern flanks of the High Plateaus. Generally each *terrain* (Trias, Jura, Cretaceous, &c.,) ends in cliffs facing the west and overlooking the great Carboniferous platform through which the Grand and Marble Cañons are cut; but the regular terraces, rising step above step, are wanting. The arrangement can be understood only by consulting the geological map and sections. It is greatly complicated by a large monoclinal flexure (Echo Cliff flexure) which throws down the country east of the Marble Cañon and Paria Plateau, and upon the slope of this monocline appear the edges of the Trias and Jura, and a little beyond it the Cretaceous. We are here concerned, however, only with certain facts which are common to the regions north of the district and to those east of it. On both of these sides the edges of the Mesozoic strata, ending in long lines of cliff above cliff, face towards the great Carboniferous platform.

And while this conception is fresh, let us turn to the western and southern sides of the district, where the Carboniferous platform itself ends in giant cliffs which overlook the sierra country beyond. In that sierra region the rocks are all of older age—Archæan, Silurian, and Devonian (?), and the elevations, except the summits of the ridges, are much less than

those of the plateaus. We may now realize that the district drained by the Grand and Marble Cañons consists of a vast platform of Carboniferous strata nearly horizontal; bounded on the north and east by the edges of abruptly terminated Mesozoic beds *ascending* cliff above cliff; and bounded upon the west and south by its own terminal escarpment *descending* to the Silurian and Archæan rocks of the sierra region.

In a preliminary treatment of the more general features of the district it is necessary to advert to the displacements which serve to define its different portions. The most striking structural characteristic is the approximate horizontality of the strata. But although the dips, except at the monoclines are very small, they are important. They rarely exceed 2° and generally are less than 1°. But as they are for the most part in one direction—towards the north—and as the distances over which they prevail are very great, the aggregate effect is correspondingly great. The summit of the Carboniferous at the base of the Permian near Kanab, five or six miles south of the Vermilion Cliffs, is about 4,400 feet above the sea. Forty miles further south, near the brink of the Grand Cañon, the same geological horizon lies at an altitude of 6,400 feet, and at the bases of the San Francisco Mountains its altitude is 7,800 feet above the sea. In the course of the discussion this widely diffused dip will appear as a factor of the utmost importance.

Allusion has already been made to the abrupt lines of displacement which traverse the region in directions which never deviate far from north and south. But some further discussion is advisable.

The great faults and flexures which traverse lengthwise the district of the High Plateaus and the Grand Cañon district form a very striking system. They are of great magnitude and are remarkable for their enormous length. In the High Plateaus they are comparatively near together, but from north to south they spread out very slightly and the area over which they extend constantly widens southwardly. In the Grand Cañon district they have their widest expansion and are separated by the widest intervals, occupying there a belt of country having a width of more than a hundred miles from west to east.

The westernmost of these is the *Grand Wash fault.* It is a feature of

the highest importance, since it is the boundary, not only of the Grand Cañon district, but of the Plateau Province itself. It drops the country on the west about 6,000 feet at a maximum. The greatest observed displacement is at the lower end of the Grand Cañon, where the lower Trias appears abutting against the lower Carboniferous. South of the river it continues for an unknown distance, still terminating the platform of the district. North of the river it diminishes in the amount of displacement, and near Saint George, on the Utah boundary-line, it appears to vanish. But the downthrow has in the mean time been shifted eastward to the *Hurricane fault.* As the Grand Wash fault diminishes northwardly so does the Hurricane fault increase.

The latter crosses the Colorado upon the western base of the Uinkaret Plateau, and is known to extend a considerable distance south of the river; but the more distant extensions of it in that direction have not yet been studied. At the Grand Cañon its displacement is about 1,800 feet, and this amount is preserved with approximate uniformity for thirty miles north of the river. It then increases until, at the point where the Virgen River crosses it, the displacement is more than 6,000 feet, bringing the Jurassic below the level of the upper Carboniferous. Here by the evanishment of the Grand Wash fault it has become the boundary of the Plateau country. It continues northward in great force along the base of the Markágunt mass and disappears seventy or eighty miles north of the Virgen.

The next fault is the *Toroweap.* It is of less magnitude and length than the others, though still considerable. It crosses the Colorado at the foot of the Toroweap Valley, which lies at the eastern base of the Uinkaret Plateau. Here its displacement is about 700 feet. It is seen to extend south of the river for a considerable distance, rather increasing in the amount of shear, or at least holding its own as far as it has been traced. But its mode of resolution remains to be investigated. North of the river it gradually dwindles and vanishes about 18 or 20 miles north of the Cañon.

The southern extension of the great *Sevier fault* also penetrates the district, but its effect is seen only in the terraces. It is a strong feature at the southernmost promontory of the Vermilion Cliffs at Pipe Spring, but its further extension towards the south cannot be great. The soil and allu-

vium at the base of the Vermilion Cliffs hide everything beneath for several miles, and beyond that no trace of the fault is visible.

The *Western* and *Eastern Kaibab displacements* will be treated so fully hereafter that no extended mention of them is deemed necessary here. They include between them the Kaibab platform. At the northern extremity of that plateau the western fault merges into the eastern and loses its individuality at once. The eastern displacement is a great monoclinal flexure. South of the river, at the head of the Grand Cañon, it appears as a gentle inclination, becoming steeper and more abrupt upon the northern side. All along the eastern front of the Kaibab it is a sharp sudden flexure, turning down the Carboniferous beds from 2,500 to 4,000 feet. It reaches far to the northward and enters the district of the High Plateaus.

The easternmost displacement is the Echo Cliff flexure. It crosses the Colorado at the head of the Marble Cañon and is known to extend at least 100 miles south of the river. Upon the northern side it reaches up to the little village of Paria at the foot of the Vermilion Cliffs, where it appears to merge with the Eastern Kaibab monocline.

The four faults west of the Kaibab, viz, the Grand Wash, Hurricane, Toroweap, and West Kaibab, drop the country to the west of them. The two monoclines east of the same plateau, viz, East Kaibab and Echo Cliff flexures, drop the country to the east of them. We may note also a general feature in the trend of these faults. With the exception of the Echo Cliff monocline their courses, though generally north and south, are curvilinear and in a peculiar way. At the base of the Vermilion Cliffs the courses are a little west of south, and thence gradually bend to due south and finally to the south-southeast. All of them appear to have this feature in common, and the result is that they include between them crescent-shaped or scimetar-shaped blocks of country. Viewed in another way we may observe that they show a tendency to maintain a parallelism with the western and southwestern boundary of the district; which boundary, as will subsequently appear, is the approximate *locus* of the old Mesozoic shore-line, from which the sediments of that age were derived. No cross faults—at least upon the northern side of the chasm—have been detected, and it may

be affirmed that none of any importance exist. They would not have escaped observation if they were present.

In the course of the present work much use will be made of the drainage system in the task of unraveling the geological history of the region, and a brief sketch of that system is deemed necessary here. The trunk of the drainage tree is the Colorado. This marvelous river, after traversing the heart of the Plateau Province for hundreds of miles, and nearly all the way in profound chasms, at length reaches the escarpment of the Echo Cliffs. Here it emerges for a moment from between opposing walls of impressive magnitude into a comparatively open space. But it is for a moment only. At once it begins to sink in the Carboniferous platform another chasm, termed the Marble Cañon. The course of the river as it leaves the Echo Cliffs is southwest, and gradually it bends to due south. As its bed descends the strata slowly rise, and at the distance of 65 miles (as the river runs) from the Echo Cliffs the abyss attains a depth of 3,600 feet. At this point the Little Colorado, a tributary coming from the south, enters it through a cañon of equal depth. Three or four miles from the confluence the main stream, hitherto flowing southward, suddenly changes its course to the west and enters the upward slope of the East Kaibab monocline. Rapidly the chasm deepens to about 6,000 feet—the increase of depth being mainly due to the fact that it penetrates a much higher country while the descent of the river meantime is immaterially small. Here begins the Grand Cañon. On the north is the Kaibab Plateau, and on the south is the continuation of the same platform as the Kaibab, at an altitude which is only three or four hundred feet lower—a difference which is very small in comparison with the depth of the chasm. Through this lofty plateau—8,000 to 9,000 feet high—the chasm extends for a distance of about 60 miles, gradually changing its direction to the northwest. This portion of the cañon will, for convenience of discussion, be called the Kaibab division of the Grand Cañon. It is the sublimest portion of the chasm, being nearly a thousand feet deeper than any other. But the greater depth is by no means the chief reason for this superior grandeur, since the relative difference between 5,000 and 6,000 feet is not so very great. But the Kaibab division is far more diversified and complex than the others and is adorned with a

multitude of magnificent features which are either wanting or much less strongly represented elsewhere. If now we consider the Marble Cañon with its southerly course, and the Kaibab division of the Grand Cañon with its west and northwesterly course, we shall perceive that these two portions of the river form a great elbow or detour to the south. This detour is named the Eastern Bend.

After passing the Kaibab division the chasm suddenly changes its course again from northwest to a direction a little south of due west, extending in an almost straight line through the Kanab Plateau, a distance of forty miles. Here the chasm is about 5,000 feet in depth, varying but little from that amount. It is also much simpler in form than in the Kaibab division. Along this portion two great side cañons, as deep as the main chasm itself, open into it; one from the north, called Kanab Cañon, the other from the south, called Cataract Cañon. The Kanab division ends at the foot of Toroweap Valley, a broad avenue about 20 miles long and two to three miles wide coming from the north. This valley is excavated only to about two-fifths of the depth of the chasm, and opens upon a broad platform in the main cañon. The fault which runs through this valley drops the country to the west, and the height of the walls where the river crosses the fault at once diminishes from about 5,200 feet to 4,500 feet. But the lost altitude is soon regained. Here begins the Uinkaret division, which is about 15 miles in length. It is very similar in character to the Kanab division. At its termination the river again changes its course to the southwest and enters the Sheavwits Plateau. As the river crosses the Hurricane fault the walls again drop and again the lost altitude is soon recovered. The general character of the cañon in the Sheavwits division is similar to that of the Kanab. In this plateau the river makes a second great detour to the south, beginning with a southwesterly course, and after running about 40 miles in this direction suddenly deflecting to the northwest. This detour is named the Western Bend. The length of the Sheavwits division is about 80 miles. At length the river emerges from this platform through a gateway 5,000 feet in depth, and as it crosses the Grand Wash fault the walls at once drop to mere banks a few hundred feet in height with easy slopes, and the Grand Cañon ends.

We may reckon the length of the entire chasm in several ways with varying results. If the line of measurement be laid along the middle of the water surface of the river, following all its meanderings in detail, the length would be about 220 miles. If it be laid along the median line between the crests of the summits of the walls with two-mile chords it would be about 195 miles. The distance between the confluence of the Little Colorado and the foot of the cañon at the Grand Wash in a single straight line is only 125 miles. The length of the Marble Cañon can be measured in only one way, and may be stated at 66 miles.

There are three principal streams which drain the terraces. The westernmost is the Virgen River, which heads in many filaments along the southern escarpment of the Markágunt. Reaching the Triassic terrace by two principal forks, it then deflects to the westward, and crossing the Hurricane Ledge leaves the Plateau Province altogether. Flowing thence southwestward, it threads its way through that dismal region which lies west of the Grand Wash and south of the Great Basin.

The second and median drainage channel of importance is Kanab Creek. It heads at the divide separating the waters which run to the Colorado from those which flow northward through the Sevier River into the Great Basin. Its springs are near that portion of this divide which lies between the Paunságunt and Markágunt plateaus. It flows due south, and enters the Grand Cañon by a mighty gorge opening midway of the Kanab division of the chasm.

The third principal drainage channel is the Paria River. It heads in the grand Paria amphitheater, receiving the wash of the eastern wall of the Paunságunt and the western front of Table Cliff. It flows about south-southeast, passing between the Paria Plateau and the Kaiparowits, and enters the Colorado at the head of the Marble Cañon.

These three rivers are the only living streams which enter the Colorado on the north side between the head of the Marble Cañon and the mouth of the Virgen—a distance of more than 300 miles. Only one of them, Kanab Creek, enters the Grand Cañon, and even Kanab Creek is dry along a portion of its bed during the greater part of the year, its waters sinking out of sight but rising again near their confluence. We cannot fail to be struck

with the absence of tributaries—this one alone excepted. The cause is obviously the arid climate. But there are also no dry cañons coming from the north, and though dry cañons are abundant in the terraces there is a conspicuous absence of them in the vicinity of the Grand Cañon. The reason for it will appear in the sequel, and it is only remarked here in a general way that the arid climate has prevailed during a very long period, and although other tributaries once existed, they have for the most part been obliterated or rendered obscure. They ceased to run with the advent of this arid climate, which came on when the present Grand Cañon had no existence, or had just begun to develop.

CHAPTER II.

THE TERRACES.

View from the southern brink of the Markágunt.—The Eocene.—The Pink Cliffs.—Correlation of the Pink Cliffs beds with the lower Eocene of the Green River basin and the Uintas.—Unconformity with the Cretaceous.—Brackish water deposits at the base.—Only the lower Eocene deposited here. Volcanic sands.—Remnants of the Eocene in the littoral belt to the southwest of the Markágunt. Sources of their materials in the Mesozoic land of the Great Basin.—The old shore line.—Outlier on the Kaiparowits.—Absence of the Eocene from the heart of the Plateau Province.—The Cretaceous.—Its extent and thickness.—Its topographical features.—Its occurrence in the littoral belt.—Its exposures in the Kaiparowits.—Its extension into the great mesas of Arizona.—Former extension westward of the great Cretaceous ocean and connection with the area of the Plateau Province.—The Jurassic.—The subdivisions of the formation.—The great cross-bedded sandstone.—Its characteristic cliffs.—Its forms on the Colob.—Absence of this sandstone from the eastern part of the province and its blending with the Trias.—The Jurassic in the littoral belt, in the terraces in the west flank of the Kaiparowits and Paria and in the Echo Cliffs.—The Trias.—Its obscure separation from the Jura.—Lithological characters of its beds.—Its appearance in the terraces.—The Vermilion Cliffs.—Its extension in the Paria Plateau and in the Echo Cliffs.—Outlying remnants in the Sheavwits Plateau and Grand Wash.—Its exposures in the littoral belt.—The Permian.—Its separation from the Trias.—Its numerous remnants over the Grand Cañon platform.—Facts of general application to the terraces.—The prevailing dip of the whole Mesozoic series towards the north.—Sudden increments of dip at the bases of the cliffs.—Attenuation of the strata towards the east.—Subordinate watersheds of the terraces.—Drainage basin of the Virgen.—Basin of Kanab Creek.—Cañons of Upper Kanab.—The Paria.—Courses of the drainage with reference to structural slopes.

In describing those subdivisions of the Grand Cañon district which are of greatest moment to the present discussion, I shall begin with the terraces terminating the High Plateaus.

Before the observer who stands upon a southern salient of the Markágunt Plateau is spread out a magnificent spectacle. The altitude is nearly 11,000 feet above the sea, and the radius of vision reaches to the southward nearly a hundred miles. In the extreme distance is the calm of the desert platform, its surface mottled with indistinct lights and shades, too remote to disclose their meaning. Against the southeastern horizon is projected the pale blue escarpment of the Kaibab, which stretches away to the south until the curvature of the earth carries it out of sight. To

the southward rise in merest outline, and devoid of all visible details, the dark mass of Mount Trumbull and the waving cones of the Uinkaret. Between these and the Kaibab the limit of the prospect is a horizontal line, like that which separates the sea from the sky. To the southwestward are the sierras of the Basin Province, and quite near to us there rises a short but quite lofty range of veritable mountains, contrasting powerfully with the flat crestlines and mesas which lie to the south and east. It is the Pine Valley range, and though its absolute altitude above the sea is smaller than many other ranges of the West, yet since their bases are comparatively low (3,000 to 3,500 feet above the sea), the mountain masses themselves are very high.

THE EOCENE.

The foreground of the picture is full of strength and animation. At our feet is the brink of a precipice where the profiles descend 800 feet upon rugged slopes which shelve away downwards and mingle with the inequalities of a broad platform deeply indented with picturesque valleys. The cliff on which we stand is of marvelous sculpture and color. The rains have carved out of it rows of square obelisks and pilasters of uniform pattern and dimensions, which decorate the front for many miles, giving the effect of a gigantic colonnade from which the entablature has been removed or has fallen in ruins. The Plateau Country abounds in these close resemblances of natural carving to human architecture, and nowhere are these more conspicuous or more perfect than in the scarps which terminate the summits of the Markágunt and Paunságunt Plateaus. Their color varies with the light and atmosphere. It is a pale red under ordinary lights, but as the sun sinks towards the horizon it deepens into a rich rose-color, which is seen in no other rocks and is beautiful beyond description. These cliffs are of lower Eocene age, consisting of lake marls very uniformly bedded. At the base of this series the beds are coarser, and contain well-marked, brackish-water fossils; but as we ascend to the higher beds we find the great mass of the Eocene to consist of fresh-water deposits.

These beds are identical in age with the lower divisions of the Eocene,

which are seen in great volume both north and south of the Uinta Mountains, in the basins of the Green River, of Bitter Creek, and of the White and Uinta rivers. Their geological relations and associations, too, are quite the same, for the same lake bottom received the deposits of the southern Uinta slopes and those of the Markágunt. Those of the Green River basin north of the Uintas appear to have accumulated in a separate lake basin communicating with the one which submerged the southern Plateau Province. The interval separating the Markágunt from the Uinta region is two hundred and fifty miles and more, but the lower Eocene is continuous between them. It occupies a marginal belt, sometimes narrow, but more frequently wide, which was once the locus of the northwestern portion and shore line of the great lake. The summits of the High Plateaus, wherever the volcanic masses are absent, disclose this formation, and its presence is decisively inferred beneath the lavas and their *débris*. A common bond between the two regions is also indicated by the physical conditions attending the deposition of these strata. The lower Eocene rests upon the underlying formations, conformably in some places, unconformably in others. Where conformity prevails, both the upper and lower series were at the time of deposition sensibly horizontal. But in many places the Cretaceous, prior to the deposition of the Eocene, was greatly disturbed and greatly eroded. And in general the base of the Eocene marks an epoch in the geological history of the country, in which an old order of events was closing and a new order was making its advent. This revolution was the transition of the region from the oceanic condition to that of an estuary and lake, and subsequently to that of dry land. The lower Eocene beds are brackish-water deposits in the basal members, while higher up they become fresh-water. The basal members are coarse and even conglomeratic in their texture, while the middle and higher ones are fine and marly. Thus is indicated the complete severance of the lake from the access of oceanic waters. Both in the Uinta district and throughout the High Plateaus these events are recorded in the same order and their meaning is the same in both.

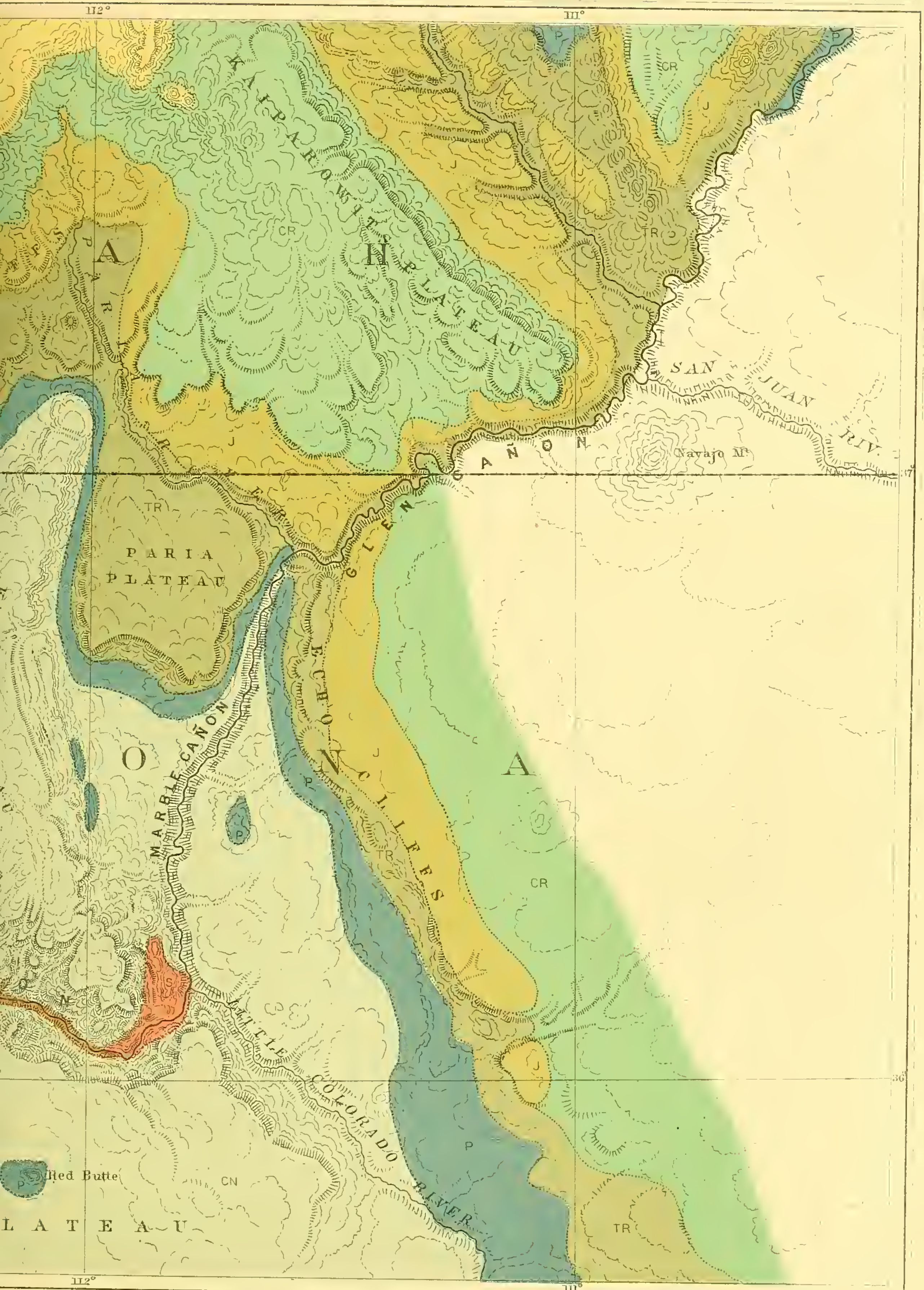
The beds now found in the southern extremities of the High Plateaus represent less than half of the duration of Eocene time. No middle and

Topography by J H Renshawe

Julius B

MAP OF THE GRAND CAÑON PLATFORM AN

Tertiary	Cretaceous	Jurassic	Trias	Permian
T	CR	J	TR	P

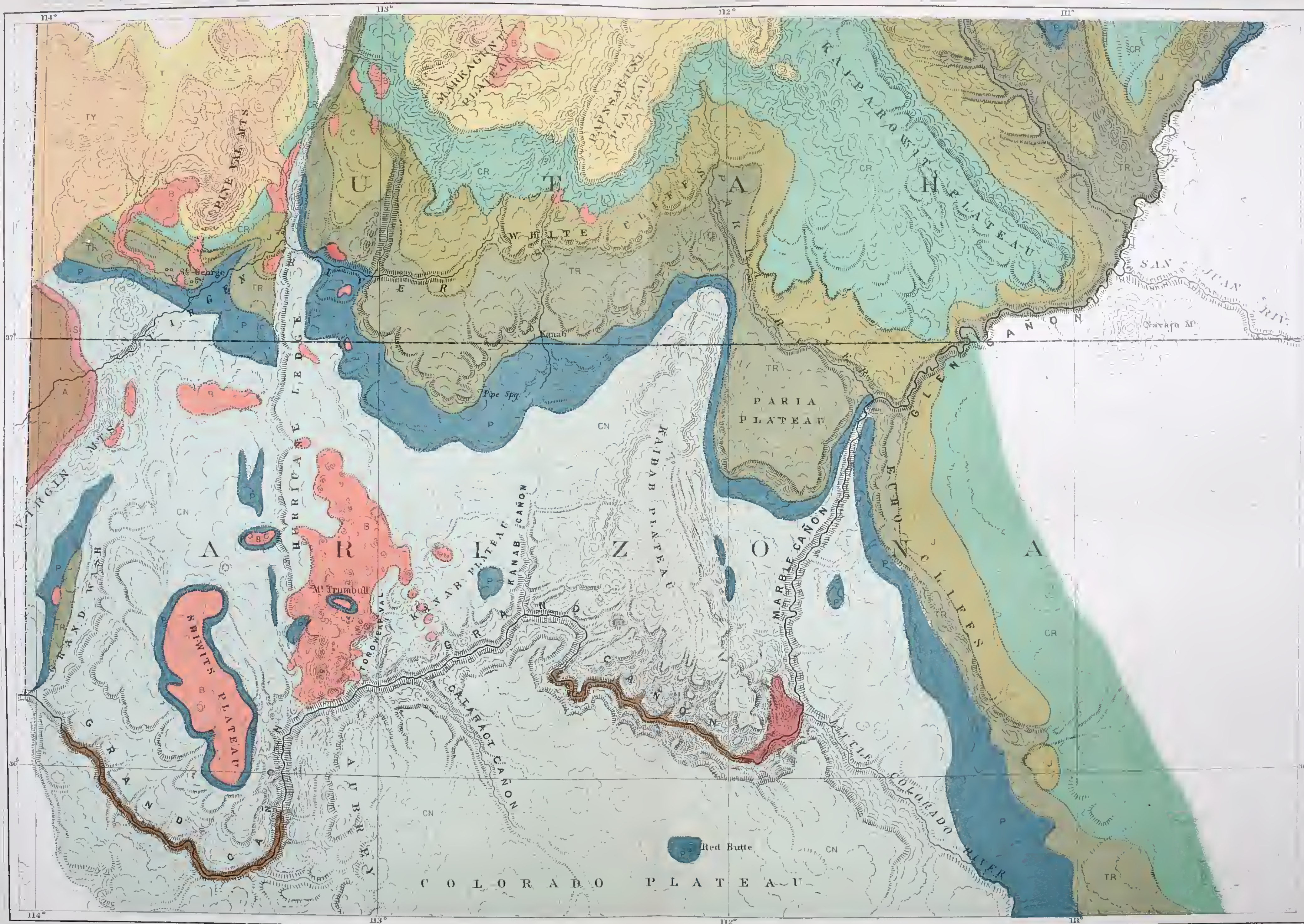


Co. lith

C.E. DUTTON, Geologist in Charge

THE SURROUNDING MESOZOIC FORMATIONS

Carboniferous	Silurian	Archæan	Trachyte Rhyolite & Andesite	Basalt
CN	S	A	TY	B



Topography by J. H. Renshawe — Julius Bien & Co. lith — C. E. DUTTON, Geologist in Charge

MAP OF THE GRAND CAÑON PLATFORM AND THE SURROUNDING MESOZOIC FORMATIONS

Tertiary T · Cretaceous CR · Jurassic J · Trias TR · Permian P · Carboniferous CN · Silurian S · Archæan A · Trachyte Rhyolite & Andesite TY · Basalt B

Scale 1:000,000

no upper Eocene strata are found there. But as we go northward towards the Uintas we find later and later formations successively appearing until upon the flanks of the Uintas the whole Eocene appears in enormous volume, exceeding perhaps 5,000 feet. Could these middle and upper Eocene masses once have existed upon the southern portion of the High Plateaus and been swept away by erosion? There is strong evidence to the contrary.

Within a few miles of our standpoint on the Markágunt are found small patches of water-laid strata consisting of volcanic sand overlying the Eocene marls, and upon these are piled massive sheets of andesite and trachyte. No apparent unconformity separates the stratified tufa from the underlying marls, and to all appearances the deposition was continuous. The inference is plain that the lacustrine age closed here amid volcanic convulsions, and that the epoch of its closure was at the end of the lower Eocene. Similar evidences are found as we examine each successive exposure to the northward, in which the summit of the lacustrine series is revealed; but with the following modification. The beds of volcanic sand grow thicker and more numerous, indicating a longer continuance of the lake the further north we trace it. And when we pass northwardly beyond the limits of the volcanic masses of the High Plateaus, we find common sedimentary beds bearing fresh-water fossils of middle Eocene age. Still further northward we find strata of later and later age, successively making their appearance until at last, within sight of the Uintas, the whole of the local Eocene is present.

These facts point to the conclusion that when the desiccation of the great lake took place, the portion which first emerged was the southwestern, or the Grand Cañon district. Perhaps when its southern boundary in eastern Arizona and western New Mexico is examined in detail we shall be led to infer an equal antiquity for the emergence of those regions, and in truth, from the little that is known of them, a suspicion is raised that it will so prove. In any event. it appears that the desiccation of the southern portion of the lake is older than that of the northern, and that its shore-line gradually receded northward during middle and upper Eocene time, leaving dry land behind it, and at the close of the Eocene the last remnant of

the lake disappeared near the southern base of the Uinta Mountains. Nor does this inference rest wholly upon the facts thus recited. Wherever the physical geology and evolution of the Grand Cañon district touches the question of time, the same conclusion presents itself, sometimes dimly, sometimes forcibly. Doubtless it will appear repeatedly and from many points of view as the discussion of the region progresses.

Inasmuch as the most prominent theme of this work will be the recital of the evidences which this district presents of an enormous denudation during Tertiary time, we may with advantage proceed to the examination of the other remnants of Eocene strata which that denudation has spared; for by the study and comparison of residual masses some valuable indications may be found showing the original condition and distribution of the primitive masses. The principal body of the Eocene strata terminates southwardly at the brinks of the High Plateaus. But there are other bodies of the same formation occurring in a fragmentary way far to the southwest. At the northeastern base of the Pine Valley Mountains some large remnants are seen, and upon the opposite side of the same range still others are found. A general idea of their distribution may be gained by adverting to the early Tertiary geography of the region lying west and southwest of the Markágunt. The Eocene strata in these parts derived their materials from land which at that age occupied the site of the present Great Basin. The shore-line of that land extended from the southern end of the Wasatch southwardly, gradually swinging its trend more and more towards the west, until it had a direction very nearly southwest. It crossed the Nevada-Utah boundary very obliquely, and reached far to the southwest in the former State. In the littoral belt in the neighborhood of this ancient shore are many remnants of lower Eocene strata. They recur at intervals as we move southwestwardly from the Markágunt through a distance of more than 70 miles, and possibly much further. West of the Markágunt and of the Grand Cañon district the Eocene lake appears to have extended as a great gulf or bight, covering much of the southern portion of Nevada, and reaching well towards southern California. But as our knowledge of the geology of those regions is very imperfect at present, it is impossible to assert anything confidently concerning the course of the

shore-line in southwestern Nevada. All that we can say at present is that a belt of remnants of littoral Tertiary strata is known to extend for more than 70 miles southwest from the flank of the Markágunt. Whether any more of them lie beyond this limit must be determined by future investigation.

Turning now to the southern escarpments of the High Plateaus, not a solitary remnant of Tertiary strata lies south of the brinks of the Markágunt and Paunságunt. But upon the Kaiparowits, 25 miles east of the Paunságunt, is a solitary outlier of Tertiary strata upon the summit of the Kaiparowits Peak. From this point southeastward not a vestige of the Tertiary is known until we reach New Mexico. This wide interval discloses strata of all ages from the base of the Trias to the summit of the Cretaceous, and beds of the latter age form a very large proportion of the surface of the country. But if the Tertiary once extended over the whole region every trace of it has probably disappeared. It is indeed a general fact that the Tertiary remnants of the Plateau Country are found in abundance around the margin of the lake in which they were deposited, but never in the central portions of its expanse.

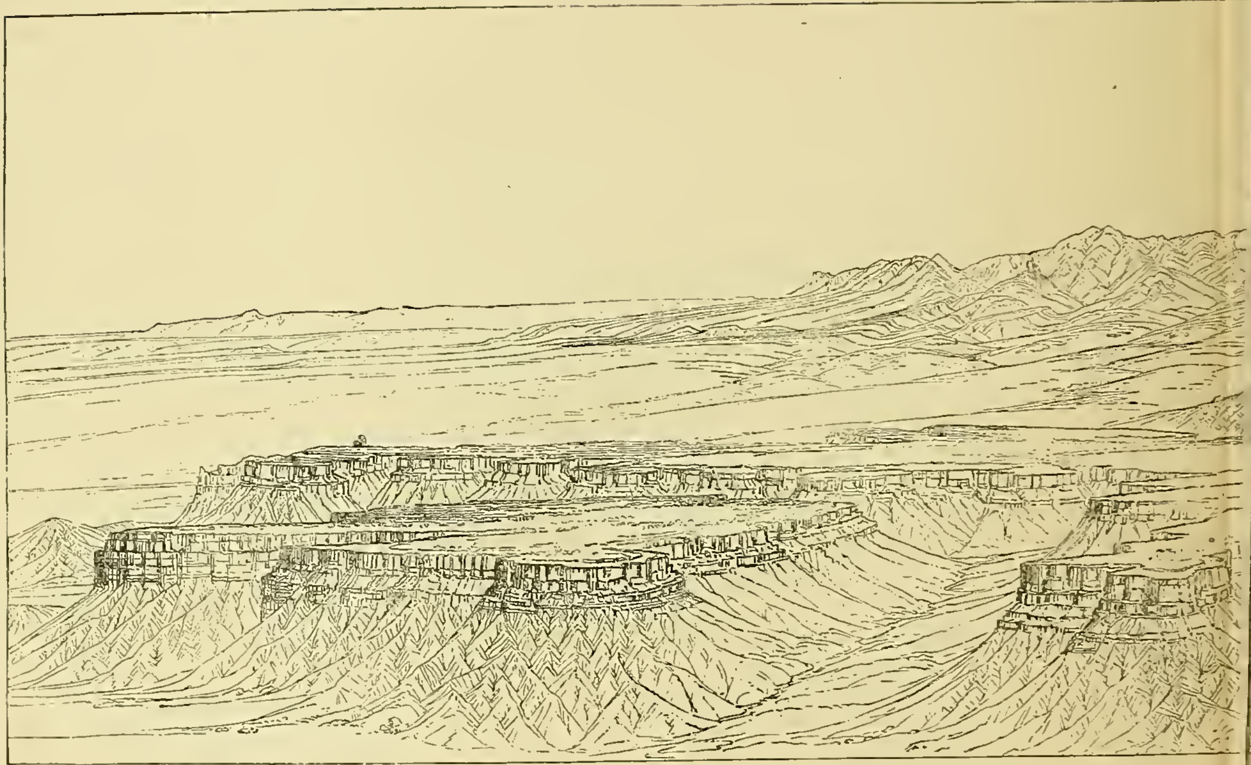
THE CRETACEOUS.

The platform immediately below the Pink Cliffs is picturesque rather than grand. Rough rolling ridges of yellow sandstone, long sloping hillsides, and rocky promontories clad with large pines and spruces, surround the valleys. These rocks are of Cretaceous age. Upon the southward slopes of the Paunságunt and Markágunt Plateaus, they nowhere present the serried fronts of cliffs, but break down into long irregular slopes much like those of common hill countries. In those superficial and merely scenic aspects which make the terraces so impressive, the Cretaceous is for the most part notably deficient; but in those deeper studies, which are of most significance to the geologist, it holds an importance not inferior to that of any other formation. It is never wanting at its proper place in the terraces, but always displays a vast series of sandstones and clay shales, varying

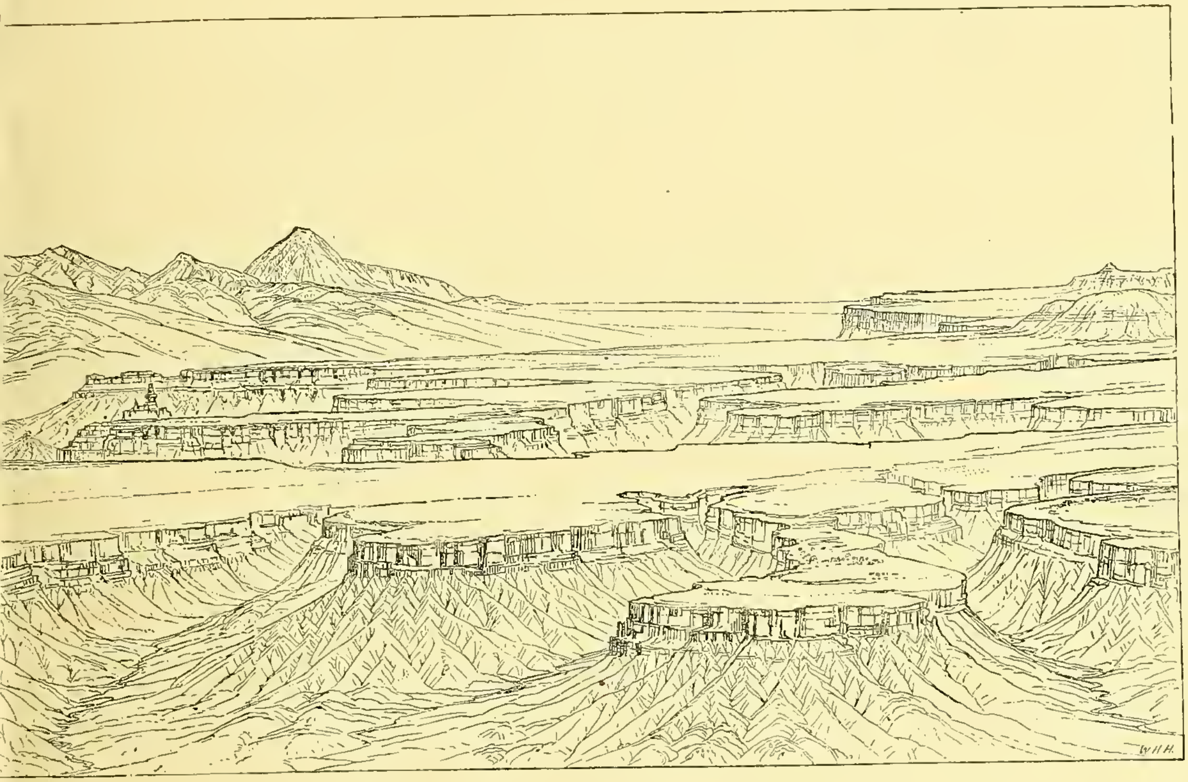
from 4,000 to 5,000 feet in thickness. Around the western and southern flanks of the Markágunt, and just beneath the summit platform, they occupy a belt varying in width from 4 to 10 miles. Around the Paunságunt their relative positions and relations are quite the same. But as we pass eastward into the great amphitheater of the Paria Valley they at length take the form of cliffs of very striking aspect. The numerous ledges rise in quick succession, step by step, from the valley bottom to the base of the Eocene mass of Table Cliff, which stands as a glorious Parthenon upon the summit of a vast Acropolis. The many superposed cliffs which constitute this stairway are severally of moderate dimensions, but their cumulative altitude is more than 4,000 feet, tier above tier, and their composite or multiple effect, intensified by the exceeding sharpness of the infinite details of repetitive sculpture, places it among the grander spectacles of the Plateau country. In their coloring, these cliffs are quite peculiar. There are no red, purple, orange, and chocolate hues, such as prevail in other formations, but pale yellow and light brown in the sandstones and blue-gray to dark iron-gray in the heavy belts of shale. The tones are very light and brilliant on the whole, the darker belts playing the part of a foil which augments rather than diminishes their luminosity.

In the region which lies west of the Markágunt the Cretaceous occurs in much the same manner as the Eocene. Like the latter formation, it is here a marginal belt skirting the Mesozoic mainland of the Great Basin. Only remnants of it have been spared. The country where they occur is a part of the sierra region, and it has been greatly shattered and distorted by movements of the same character as those which hoisted the Basin ranges and which warped and tilted their strata. Erosion, acting upon these masses, wasted them enormously, and wherever we find the Cretaceous we perceive that its preservation has been due to a mere accident of the position in which these displacements have left it or to the protection of some great volcanic overflow.

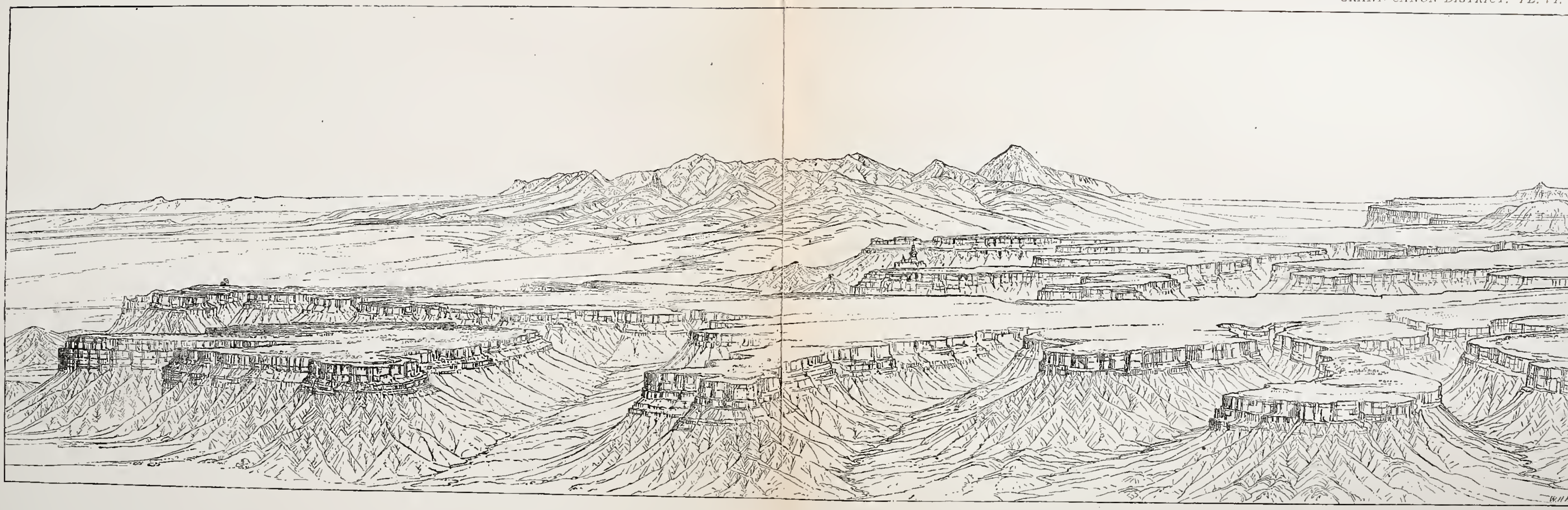
In the terraces of the High Plateaus the entire Cretaceous system is preserved as a step in the stairway; but it has no outliers. It projects southward from beneath the Eocene Cliffs and is in its turn cut off. Beyond



MESA VERDE.—



ETACEOUS.



MESA VERDE.—CRETACEOUS.

the proper margin of its own terrace no vestige of it appears to the southward.

Proceeding eastward to the Kaiparowits the Cretaceous presents itself in a manner which is highly significant, and which merits careful examination. We have already remarked that the Eocene is wholly absent from the interior spaces of the Plateau Country. From the places of its exposure in the southern parts of the High Plateaus to the places of its exposure in Colorado and New Mexico is an interval of 180 to 240 miles. But while the Eocene is wholly wanting in this great intervening space the Cretaceous occurs in very large masses, forming probably at least half of the surface of the country. The Kaiparowits Plateau is a broad belt of Cretaceous strata reaching out southwardly from the Aquarius Plateau and from Table Cliff (an outlier of the Aquarius). At a distance of 60 miles from the latter the Colorado River cuts right across the Kaiparowits, forming the great gorge of the Glen Cañon. South of the river the platform resumes its character, and the Cretaceous spreads out into great mesas deeply dissected by cañons tributary to the San Juan. These Cretaceous mesas cover almost the entire northeastern quarter of Arizona and reach indefinitely eastward. In truth there is little doubt that these strata are the continuation of the Cretaceous formations which overspread the greater part of New Mexico, Texas, Colorado, the Indian Territory, and the Great Plains at large between the Rocky Mountains and the Missouri River. It is already a foregone conclusion that the Cretaceous sea, which extended from the Gulf of Mexico northward towards the Arctic Ocean, also extended west, covering the Plateau Province, and reached far into Arizona and even into southern Nevada. Perhaps it joined the Pacific through a broad strait running between the Great Basin area on the north and the sierra country of western Arizona on the south. But this we cannot as yet prove, though many facts seem to indicate it. At all events if the Atlantic did not join the Pacific here the separation of the two oceans was only by a narrow belt of land.

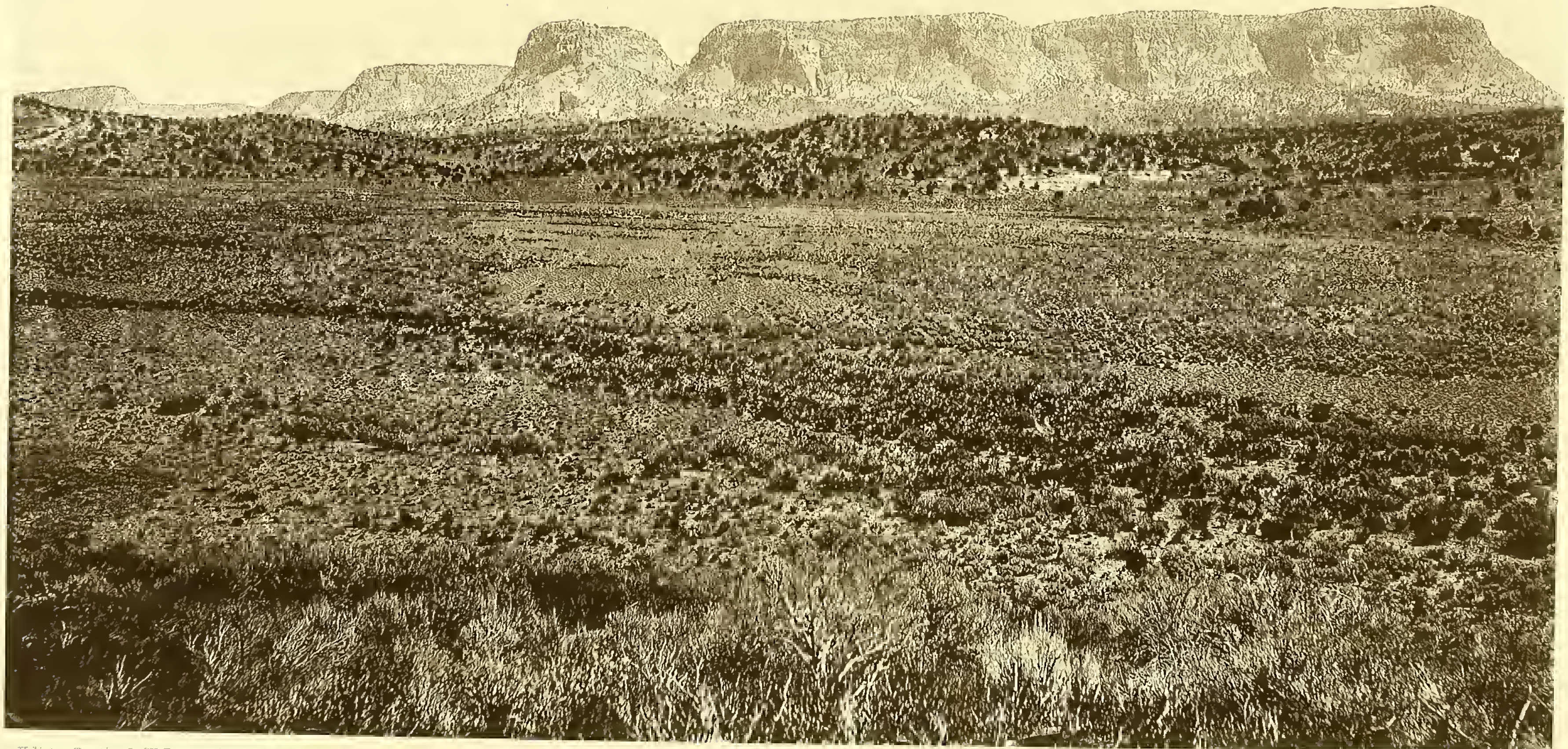
The western wall of the Kaiparowits here marks the limit of the Cretaceous formation. Formerly, indeed, its strata extended much further westward, but they have been swept away from the interior spaces of the

Grand Cañon district. The Kaiparowits wall, broken for a moment at the mouth of the Glen Cañon, resumes its course south of the river on the summit of the Echo Cliffs and reaches 80 miles beyond the Colorado. Its meaning here is the same as that of the terminal edges of the Cretaceous in the terraces of the High Plateaus. In the terraces we find the edges of the Mesozoic system forming the *northern* margin of the Grand Cañon district. In the Kaiparowits front and in its continuation along the line of the Echo Cliffs we find the edges of the same strata forming the *eastern* margin of the district. Thus, upon two sides of the Grand Cañon platform, the Cretaceous, preserved in full force, presents the abruptly terminated edges of its strata towards that platform and overlooks it. The littoral belt of southwestern Utah and southern Nevada may be looked upon as part of a third side of the district, disclosing a fringe of Cretaceous remnants. Altogether, the eroded edges of this formation are found upon about two-thirds of the periphery of the Grand Cañon district. Of the remaining third of the circuit our knowledge is very imperfect, for it has not been geologically explored with thoroughness.

THE JURA.

To the student whose mind is engaged chiefly with problems of stratigraphy the Jura-Trias system of the plateaus, (and the Permian may be considered as indissolubly linked with it), is a most alluring field of study. True, it yields him more questions than answers, but the questions are full of suggestion, opening many avenues of thought which he is fain to follow. All things considered, this series is probably the most conspicuous and typical one in the Plateau Country, and it there displays a development grander and more extensive than in any other region of the world.

The division of the Jurassic from the Trias is often difficult to make. The primary reason is the want of fossils. The uppermost members of the Jurassic contain an abundant marine fauna; but thence downwards we find no organic forms sufficient for purposes of discrimination until we reach the lower members of the Permian. A few plants, an abundance of silicified wood, a few unrecognizable dermal scutes of fishes, are all that the great



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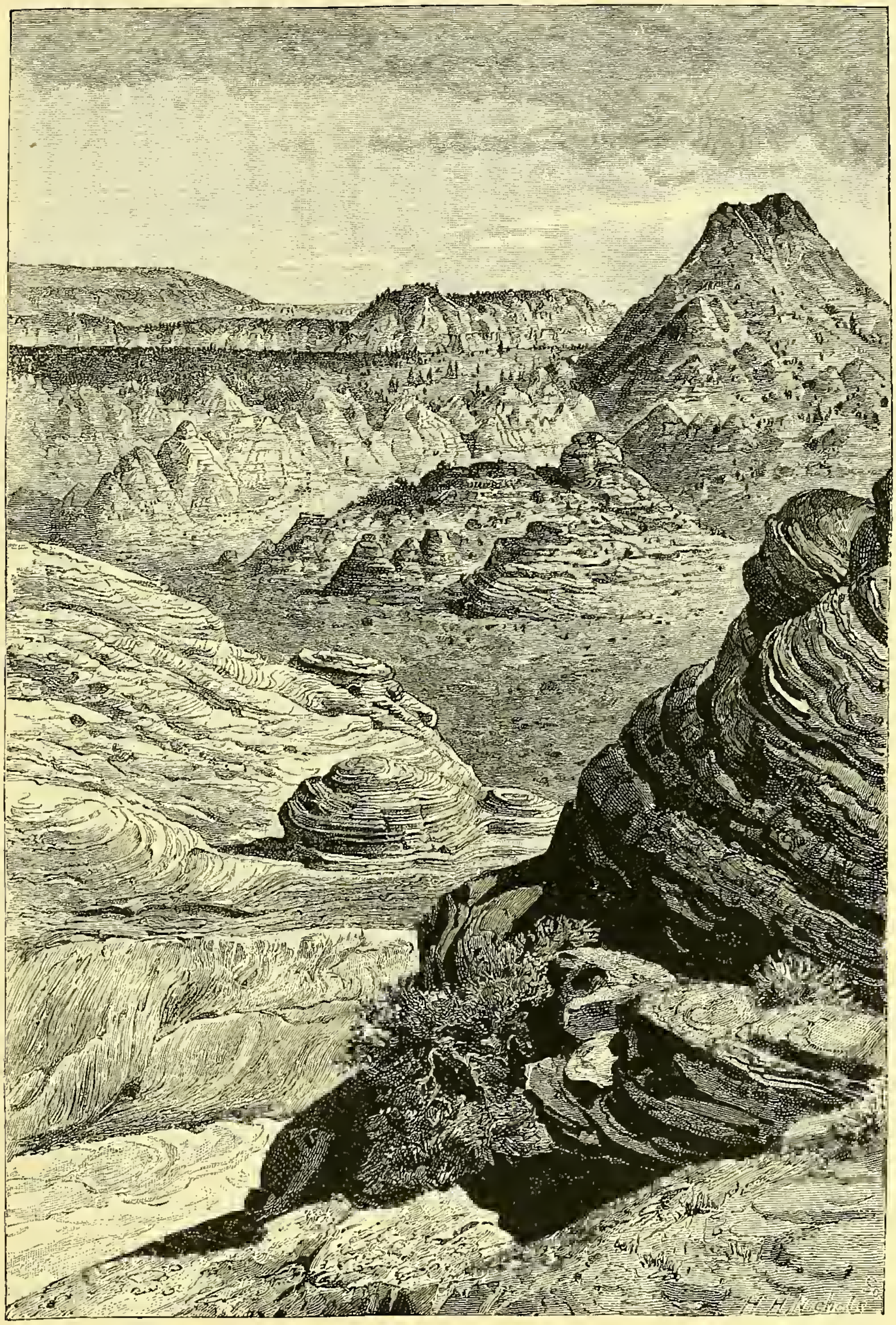
JURASSIC WHITE SANDSTONE.

succession of intervening beds has thus far yielded. The provisional separation now adopted is reached by tracing the series continuously into distant regions where the discrimination can be made, and correlating the sections of the two localities. In very few, if any, other portions of the world would this be possible; but here the formations are so persistent over enormous areas, and they retain throughout so unmistakably their lithological characters, both *en masse* and in their component members, that the problem is relieved of most of its doubts and difficulties. The Jurassic, as thus separated, consists of a series of bright red, fossiliferous shales resting upon a very massive bed of white sandstone nearly a thousand feet thick. The shales, which are from 300 to 500 feet in thickness, consist of beds which vary much in quality, some being calcareous, some gypsiferous, and others thinly bedded sandstones. Their interest is chiefly palaeontological, since the calcareous layers abound in typical Jurassic fossils, which fix their horizons with certainty. But the portion to which the attention is most powerfully attracted is the great mass of white sandstone; and a wonderful mass it is.

From summit to base it appears to be one indivisible stratum. Here and there signs of a division are suspected, but closer scrutiny shows that they are produced by the contact of one plexus of cross-bedding with another, or by some peculiarity in the texture of the rock, or by weathering, or some other cause not affecting the dominant fact. From top to bottom it is, so far as observed, remarkably homogeneous and constant. The cross bedding is unique. It is never wanting, and covers the entire face of every exposure with a strange arabesque, or a filagree, as beautiful as frostwork. The weathering of the surfaces etches out the more refractory laminae, causing them to project from six to ten and sometimes twelve or even fifteen inches beyond the softer ones. The bright tone of the rock face, chased across by the dark shadows of deeply etched layers, brings out with the strongest emphasis the graceful waving of myriads of these curves. The Jurassic sandstone is also conspicuous for its cliffs. Every formation in the district presents cliffs, and each formation has its own style of architecture and sculpture, which is as distinctive as its lithological constitution; for upon that constitution the style depends. The style of the Jurassic sandstone is

characterised by a peculiar boldness and an extreme simplicity which is even severe. Its walls are perfectly plain, with neither horizontal nor vertical lines; of decoration there is not a trace, except the cross-bedding, which becomes invisible at distances sufficient to render a general view of the fronts effective. A notable feature is the absence of talus; or, if it be present, its very small proportions. Almost all other cliffs have a sensibly vertical upper portion, suddenly changing to a slope of 30 to 35 degrees in the lower portion, and this greatly enhances their beauty and relieves their monotony. No such decoration is seen in the Jurassic cliffs, which are as devoid of ornament as a fortress. It might be imagined that such fronts would be monotonous and tame, and once seen would soon lose all interest. Let us not underrate the versatility and resources of Nature, nor question her good taste, for she has made these walls as full of life, variety, and expression as any others, and yet has conserved the noble dignity of which simplicity is an essential part. Instead of a straight, unbroken palisade, which would be tame indeed, the wall is exceedingly sinuous and angular, here throwing out a bastion, there deeply recessed by a bay. Many chasms are cut through it, cleaving from top to bottom. Many great buttes and isolated temples stand out from the parent mass, and the masses so isolated often weather into domes and half-domes of bald white rock which look a calm defiance of human intrusion. Occasionally, the austerity of these forms is exchanged for those of the opposite extreme, as if Nature were tired and impatient of all this solemn dignity, and the proverbial step from the sublime to the ridiculous is actually taken. Looking southward from the brink of the Markágunt the eye is attracted to the features of a broad middle terrace upon its southwestern flank, named The Colob. It is a veritable wonderland. It lies beyond the Cretaceous belt and is far enough away to be obscure in its details, yet exciting curiosity. If we descend to it we shall perceive numberless rock-forms of nameless shapes, but often grotesque and ludicrous, starting up from the earth as isolated freaks of carving or standing in clusters and rows along the white walls of sandstone. They bear little likeness to anything we can think of, and yet they tease the imagination to find something whereunto they may be likened. Yet the forms are in a certain sense very definite,



A MIDSUMMERDAY'S DREAM.—JURASSIC.—ON THE COLOB.

and many of them look merry and farcical. The land here is full of comedy. It is a singular display of Nature's art mingled with nonsense. It is well named the Colob, for the word has no ascertainable meaning, and yet it sounds as if it ought to have one.

Nor are these the only forms which the Jurassic discloses. Here and there blank faces of the white wall are brought into view as the sinuous line of its front advances and recedes. Isolated masses cut off from the main formation, and often at considerable distances from it, lie with a majestic repose upon the broad expanse of the terrace. These sometimes become very striking in their forms. They remind us of great forts with bastions and scarps nearly a thousand feet high. The smaller masses become regular truncated cones with bare slopes. Some of them take the form of great domes where the eagles may build their nests in perfect safety. But noblest of all are the white summits of the great temples of the Virgen gleaming through the haze. Here Nature has changed her mood from levity to religious solemnity, and revealed her fervor in forms and structures more beautiful than anything in human art. But we shall see more of this hereafter and from much more advantageous stand-points than the summit of the Markágunt. There only faint suggestions of the reality are given. We only perceive in imperfect detail some throngs of towers, snow-white above and red below, the bristling spires of ornate buttes, or a portion of the grand sweep of a wing-wall thrust out from some unseen façade. None of them appear in their full relations to the whole, and all of them are weakened, faded and flattened by the distance.

The Jurassic white sandstone seems to be peculiar to the northern and western portions of the Plateau Province. In southern Colorado and western New Mexico, no stratigraphic member has yet been found which can be identified with it. There remains, however, the possibility that in those more easterly regions the Jurassic sandstone may form the upper part of the sandstone series now reckoned as Triassic. Some color is given to this view by the following facts. As we pass southeastward from the Aquarius, or from the Kaiparowits across the heart of the Plateau Province, we find that the exposures of the Jura and Trias both undergo gradual changes of aspect. Both formations grow thinner. While they are powerfully con-

trasted in the terraces—the Jura being one vast indivisible mass of white sandstone—the Trias being composed of very many thin and often shaly beds of most intense color—yet in proceeding southeastward the Trias loses many of its layers, and those which remain are thicker and more massive; while the Jura gradually becomes red and shows here and there well-marked planes of subdivision. In a word, the two formations become more and more alike as we trace them southeastwardly. Between the Glen Cañon and the Triassic exposures of New Mexico is an interval of 80 to 120 miles in which no explorations of a critical character have been made, and we are therefore ignorant of the nature of the transition by which in this unexplored interval the identity of the Jurassic sandstone is lost. So far as present knowledge is concerned we are at liberty to suppose (1), either that the Jurassic sandstone thins out completely in the interval, or, (2), that it becomes the summit of the presumed Trias of New Mexico and cannot be distinguished from it. The sandstones of both formations are alike destitute of distinguishable fossils.

Like the Eocene and the Cretaceous, the Jurassic has its littoral belt skirting the shore of the old Mesozoic mainland of the Great Basin. All the way from the Wasatch southward through central and southwestern Utah, thence obliquely into Nevada, without known limits, are found the detached exposures of this formation, faulted and displaced after the manner peculiar to the region. Around the southern flanks of the Markágunt and Paunságunt the exposures of the Jurassic are very grand and impressive. Here it is no longer displaced from sensibly horizontal positions but shows many buttes and outliers. None of them are far distant from the principal mass. Further eastward the formation is disclosed in an equally conspicuous manner in the Paria amphitheater. Upon the eastern side of this amphitheater it forms the base courses of the Kaiparowits, and descending eastward by a monoclinal flexure it disappears beneath the immense masses of Cretaceous strata which constitute the body of that plateau. All along the western wall of the Kaiparowits, as far as the Colorado, it holds this relation, exposing its edge upon the upturn of a monocline at the foot of the plateau wall. Beyond the Colorado the same relation continues in the Echo Cliffs, along the base of which runs the same flexure; and high above the Trias, but beneath the Cretaceous, the Jurassic appears duly in its

JURASSIC TERRACE.—THE COLOB.

proper place. But there are some other exposures which merit particular notice. They are found upon the summit of the Paria Plateau, a mass of Triassic and Permian strata of great extent, which has been spared in the general denudation. These Jurassic remnants are far away from the principal body. A distance of nearly 35 miles separates the remotest one from the Jurassic terrace on the north, and about half that interval lies between them and the same formation at the foot of the Kaiparowits. These outliers, situated so far out in the heart of the Grand Cañon district and within a few miles of the Colorado, are noteworthy as fragments of evidence indicating the former extension of the Jurassic over the entire surface of the denuded platform drained by the Grand and Marble Cañons.

The extension of the Jura south of the Colorado and its exposure in the line of the Echo Cliffs has been traced for nearly 60 miles. Its mode of resolution there is at present unknown, and must be ascertained by future exploration. Enough has been learned, however, to establish the fact quite positively that its general relations to the Grand Cañon district are in all essential respects the same as those of the Cretaceous above it and of the Trias beneath it. Its broken edges wall the district on two sides, the north and east, and its littoral belt along the Mesozoic shore line of the Great Basin goes far towards establishing its former existence along a great part of the third or western side. Finally, the occurrence of advanced outliers upon the Paria Plateau extend it far out into the interior spaces of the Grand Cañon district.

THE TRIAS.

The splendor of the terraces culminates in the Trias. It is separated from the Jurassic at the provisionally adopted horizon by a conspicuous change in the aspect of its component strata and in the grouping and habit of the whole series. Sometimes, however, the dividing horizon is obscured by a transition from one to the other through a gradually changing mass of sandstone; but more frequently the passage is abrupt. The Jurassic sandstone is without a likeness in any other formation, and the sandstones of the

Trias can be distinguished from it miles away. One of the most conspicuous characteristics of the latter series is the very great number of distinct beds or layers. Most of them are but a few feet in thickness, and there is but one stratum which attains very great dimensions. In lithological characters the series is highly variable. The majority of the members are common sandstones, and these predominate most in the upper portions. In the middle part they still preponderate, but are individually thinner and are more often separated by shaly layers and not unfrequently by bands of almost pure gypsum. In the lower portions sandy and argillaceous shales of wonderful color predominate; but nowhere is even a solitary band of limestone known to occur. Lime, indeed, is found in these rocks and is tolerably abundant, but it is always in the form of gypsum or occasionally of selenite.

The Trias makes its appearance upon the extreme outer flank of the Markágunt, a little north of the Mormon town Cedar, rising by a fault out of the valley alluvium. With a constantly expanding exposure it extends southward along the upthrow of the Hurricane fault until the whole of its great mass comes to the surface; then broadening out into a wide terrace, it gradually sweeps around the southwestern limit of the Colob over into the valley of the Virgen, where it breaks into cliffs, temples, and buttes of ineffable splendor and beauty. Thence, with a still wider terrace, bounded by magnificent cliffs, it stretches to the southeast as far as Pipe Spring Here is the southernmost promontory, from which it trends away to the east-northeast in proportions considerably diminished, but still vast and imposing, as far as the Paria River. The distance is more than 100 miles, in which the sinuosities are not reckoned; and throughout this entire sweep it presents to the southward a majestic front richly sculptured and blazing with gorgeous colors. The cliff line is exceedingly tortuous, advancing in long promontories, with bays and broad cañon valleys setting far back into the Triassic mesa like a long stretch of coast line gashed with fiords. Perhaps the contour of a maple leaf may be a suggestive analogy.

The altitude of the cliffs is greatest in their western portions, where it often exceeds 2,000 feet, while in the portion reaching from Pipe Spring to the Paria it seldom exceeds 1,400 or 1,500 feet. In the deep bays it is still

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VERMILION CLIFFS AT KANAB.

less, because there is a slight dip back from the crestline, and because the alluvial slope leading up from the outer plain rises through a greater distance and reaches higher up on the breast of the wall at the heads of the amphitheaters.

At Paria settlement the wall for a time suddenly ends, for the drop of the Eastern Kaibab monocline brings its summit to the level of the general surface. But to the southward the upper Trias spreads out for a great distance to form the surface of the Paria Plateau. Along the eastern base of the Kaibab the cliff at length begins to rise again out of the earth with unchanged forms and lineaments. At the head of House Rock Valley it appears first as a low cliff looking westward towards the Kaibab, and as it stretches to the south it grows steadily in magnitude. Gradually it swings off from the Kaibab, assuming a more easterly and finally a northeasterly trend, until it reaches the Echo Cliffs at the head of the Marble Cañon. From this point its trend is instantly changed to the south, and in this direction it continues for 60 miles as the main escarpment of the Echo Cliff. Beyond that the Trias breaks up into mesas, terraces, and buttes, covering a great area with numberless outliers or limited platforms, here disappearing beneath the Jurassic and Cretaceous or vast floods of Tertiary lavas, there eroded over spaces of varying width and disclosing the Permian and Carboniferous below. In that distant region its definite topography is unknown; we only know its most general expression. South of the terraces the Trias is wholly wanting. But in the colossal mass of San Francisco Mountain, 50 miles south of the Colorado, Mr. Gilbert discovered a small remnant of it rescued from the general wreck by the lavas which once completely buried it.

In the northern part of the Sheavwits Plateau a large Triassic area is found. It lies at the base of the Hurricane ledge, and has a marked dip to the northward. The Hurricane fault has raised the Carboniferous above the summit of the Trias, and while the Carboniferous strata on the lifted side are horizontal the Triassic beds on the thrown side have a marked dip in a direction parallel to the course of the fault. This arises from the rapid increase in the amount of shear or displacement of the Hurricane fault. In other words, the thrown beds are sunk lower and lower along the

northward extension of the fracture, until at length, near the Virgen, the Jurassic comes in above the Trias and is depressed below the summit of the Carboniferous. This Triassic mass is in reality an outlier of the main formation, and extends about 15 to 18 miles in advance of the principal mass in the terraces. It is in some sense the counterpart of the Paria Plateau, which is a very advanced salient of the Triassic terrace.

There are also considerable bodies of this formation in the valley of the Grand Wash, extending from Saint George, Utah, southward to the Colorado. The remotest one occurs near the mouth of the Grand Cañon. Here the Trias abuts against the base of the Carboniferous in consequence of the gigantic displacement of the Grand Wash fault. Not all of the series, however, is present here, the summit members having been removed by erosion.

The Trias, like the superior formations, has also its littoral belt along the Mesozoic shore-line of the Great Basin It occurs in southern Nevada in very heavy masses much distorted and faulted. The greatly disturbed attitudes of its strata begin as soon as we pass west of the Hurricane and Grand Wash faults, and they have all those peculiarities which characterize the Basin system. East of those great faults the strata are but little affected by vertical movements, except at the sharp lines of the few principal dislocations, and are seldom inclined more than one or two degrees.

In the foregoing accounts of the distribution of the Mesozoic strata it will be observed that their eroded edges are situated peripherally about the Grand Cañon district. None of them completely encircle it. In the case of the Cretaceous one-third of the circuit is unknown in detail, and such knowledge as we have leads us to presume that in this part of it few remnants may exist and perhaps none. In the case of the Jurassic the circuit is also incomplete, but some important outliers are found occupying very advanced positions out in the interior spaces of the district. In the Trias the circuit is much more nearly completed, there are more outliers, and they are still further advanced into the interior of the Grand Cañon platform. The gaps in the Triassic circuit are still large, but the detached masses of it remaining are so important, and their situations so suggestive, that the mind has little difficulty in closing it up. This configuration of

the eroded edges of the Mesozoic system and the distribution of the outliers point strongly to the conclusion that all of its formations once stretched unbroken across the whole Carboniferous platform which drains into the Grand and Marble cañons, and that during Tertiary time they have been removed from it by erosion. The dimensions of this platform are indeed vast, being in round numbers about 13,000 or 14,000 square miles. Before accepting the conclusion that a denudation so extensive has really occurred, the geologist needs to be assured that the Mesozoic strata were really deposited over the whole area. The deposits of that age in other parts of the world are often of a very local character. Their continuity is frequently broken by the intervention of land areas; their bulk varies much from place to place; members which have great volume in one locality have only a nominal one in another, or perhaps have no assignable counterpart or equivalent whatever in other regions. May it not have been so here, and may not the great denudation be too hasty and too large a conclusion from imperfect premises? The answer to this question will depend largely upon the facts disclosed in the interior of the Grand Cañon district, and upon facts of structure which will be treated of in other parts of this work.

THE PERMIAN.

The idea of a terrace is not so typically represented in the Permian as it is in the superior formations. In many parts of the great stairway it clearly forms the lowest step; in others it forms one cliff with the Trias; in still others it is beveled off and covered with alluvium. On the whole it is more frequently presented as a distinct terrace. There is another qualification which requires some mention, because when we refer to the geological map to study the surface distribution of the strata we should find some anomalies unless the point referred to were duly explained.

Wherever we encounter a cliff which discloses the upper Permian beds we find at the summit of the escarpment a band of pale-brown sandstone of very coarse texture, often becoming a conglomerate. Its thickness is usually from 40 to 75 feet. In a few places it is wanting from its proper

horizon, and in some others its thickness becomes more than 100 feet. But on the whole it is a remarkably persistent bed, and its persistence is all the more striking when we consider the coarseness of its texture; for no beds are so variable as the coarse ones. This member has been named by Powell the Shin-á-rump Conglomerate. The name Shinárump he also applied provisionally to a large group of beds in which the conglomerate is included. For several years it was thought very probable that these beds were a part of the Triassic system, though no positive proof could be cited to sustain that presumption. In the summer of 1879 Mr. C. D. Walcott, of this survey, at length found some limestone bands near the base of Powell's Shinárump, which seem to establish pretty conclusively their Permian age. But the fossils so far discovered have only a small vertical range, and lie near the base of the group. Above them are many hundred feet of beds which yield no fossils at all. While some of them are unquestionably Permian, it still remains to find the horizon where the Permian ends and the Trias begins. The Trias is as destitute of fossils as the Permian, excepting, however, some which are useless for determining age. In cases like this the geologist finds himself in trouble. He is quite sure that he has beds of two distinct ages; and he must, for purposes of discussion, separate them somehow; if not by a natural and unmistakable dividing horizon, then by an arbitrary and provisional one, subject to amendment by future research. As we examine the Triassic series from the middle downwards the various beds are so much alike in general character that a divisional horizon seems impossible. And if we examine the Permian upwards the same similarity is observed. The only member which forms a sharp contrast is the Shinárump conglomerate; and this stratum was selected by Mr. Walcott for the plane of the division. Much more to the purpose is the fact that the conglomerate rests unconformably upon the Permian shales below. The unconformity, however, is by erosion only without any discrepancy of dip. The shales were slightly eroded before the conglomerate was laid down, but neither in the emergence nor in the following submergence was the rigorous horizontality of the beds at all disturbed. Adopting the plane of unconformity rather than the stratum itself as the dividing horizon, the conglomerate obviously becomes the basal member of the Trias.

Mr. Walcott's conclusion is no doubt the best which can be reached with our present knowledge, but it is very inconvenient and awkward to the geologist who is required to map the distribution of the strata and their topographical features. In all of the other formations each group forms its own terrace or series of terraces. As we descend them we find ourselves, when we reach the foot of the Eocene cliff, upon the summit of the Cretaceous. Reaching the foot of the Cretaceous cliffs, or slopes, we are upon the broad expanse of the Jurassic platform. Descending the Jurassic, we find the Trias coming out from the base of the Jurassic Cliffs; but when we descend the Vermilion Cliffs, we have not reached the Permian. The Trias is still beneath us, pushing out its basal member, the Shinárump conglomerate, clear to the crest-line of the Permian wall. In the Jurassic terrace and in its terminal cliff we find none but Jurassic strata. Similarly, also, in the cliffs and terrace platforms of the Cretaceous and Eocene; but the Permian terrace is everywhere sheeted over with a solitary stratum of the Trias. Somehow we cannot help thinking that the conglomerate has no business there, and that it ought to have been cut off at the base of the Vermilion Cliffs, or else it ought to be relegated to the Permian. In delineating the distribution of the formations by means of colors on the map, the ordinary practice would require us to extend the Trias to the brink of the Permian Cliffs, for in such delineations we only profess to show the surface exposures of the several groups; but this would confound the Permian terrace with the Trias, and obliterate the individuality of the former, whereas in the topography both are as distinct as land and water. To preserve this distinction the Shinárump is denoted in the large scale maps by special modifications of the color, which are to be interpreted as meaning merely an arbitrary subdivision of the Trias. In the small scale maps, which are designed to express physical rather than stratigraphical facts, I have thrown the Shinárump into the Permian.

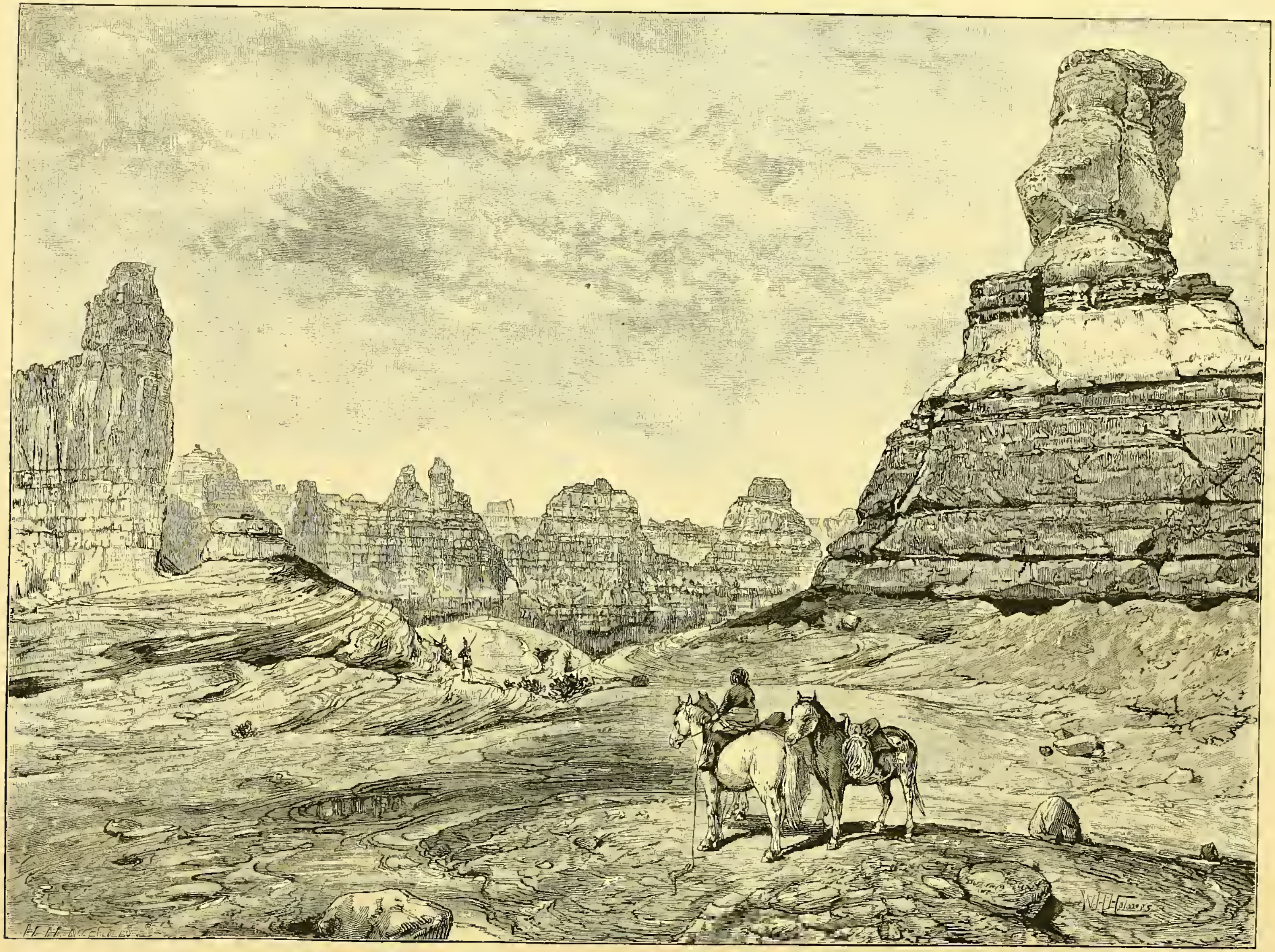
The Permian beds consist of sandy clay-shales in very many thin beds and a few thin beds of impure limestone. They are very striking on account of their dense, rich colors, which are sometimes also wonderfully delicate. They are belted in a surprising way. Horizontal streaks of chocolate, purple and red-brown are interstratified with violet, lavender, and

white. Perhaps the richest tone is the red-brown, which is almost exactly like the color of the fumes of nitrous acid. Lower in the series are layers of a peculiar shade of Indian red, alternating with grayish white. In the lower Trias and Permian the colors reach their climax. Surely no other region in the world, of which I have any knowledge, can exhibit anything comparable to it. Wonderfully even is the bedding. Thin layers may be traced for miles without showing any variation of thickness, color, or texture. In the escarpments the weathering has etched out the harder layers, leaving a line of shadow in the places of the softer layers, and this greatly emphasizes the stratification and gives it finer detail.

The Permian has many outliers and buttes in the heart of the Grand Cañon district; indeed, the entire platform is spotted with them. Usually only the basal members of the Permian remain, but in quite a number of instances the entire series is preserved. The most notable ones are found in the Mounts Trumbull and Logan, on the Uinkaret Plateau, and in the Red Butte south of the Kaibab. So far as this formation is concerned the evidence of its former extension over the entire district is complete upon stratigraphical data alone. The numberless remnants found almost everywhere throughout its expanse are so many stepping-stones at easy intervals which the mind uses in striding from one end of the region to the other with its burden of inquiry, and the way to a positive conclusion is easy and sure.

FACTS OF GENERAL APPLICATION TO THE TERRACES.

Having thus recited the principal and more obvious features of the Mesozoic formations of the terraces, it remains to examine some important facts which apply to the whole of them. The first one to be noted is a slight but universal dip to the north of all strata exposed in the terraces. This dip on the average is less than two degrees, but here and there inclinations as great as four or five degrees may be seen. This dip is very general throughout the terraces. Its effect is to make the altitudes of the higher or more northerly platforms less—or, conversely, to make the altitudes of



LAND OF THE STANDING ROCKS.

the lower and more southerly terraces greater—than they would be if the whole series were horizontal. In the entire series of beds which are exposed, the aggregate thickness from the top of the Carboniferous to the summit of the local Eocene is not far from 10,000 feet, but the summit of the Eocene at present lies only about 5,000 to 6,000 feet above the Carboniferous platform of the Grand Cañon district. Thus, if the strata were horizontal, we should in ascending the terraces go up 10,000 feet, but the dip to the northward gradually carries down the horizons so that in crossing the edges of 10,000 feet of strata we only gain 5,000 to 6,000 feet in altitude. We find this same northward dip prevailing in the Carboniferous to the southward, and it is a feature of great moment in the studies which are to follow.

Looking a little more in detail we find a very striking group of subordinate facts in connection with these dips. At the base of each terminal cliff the dip suddenly increases for a short distance and still further southward diminishes again. The strata in the median parts of any given terrace are very nearly horizontal and have inclinations scarcely exceeding one degree. But as we cross such a terrace northwards and approach the front of the wall terminating the next higher terrace the inclination becomes three or four degrees, and the beds on which we stand are seen to descend beneath the talus or alluvial slope in front of the wall. The mind here instinctively suggests that this may be due to a general settling down of the earth beneath the abrupt increase in the gross weight of the great bodies of superposed strata. Or, inversely, that the removal of a corresponding mass in front of the trenchant cliff-lines has permitted in some measure the assertion of the laws of plastic equilibrium. The northward dip of the strata and their local increments at the bases of the cliffs is represented in the sections (Plate III).

ATTENUATION OF THE STRATA TOWARDS THE EAST.

Another point to be noted is that the strata slowly diminish in thickness from west to east. The attenuation, however, is ordinarily very slow and gradual, and the observer would have to travel many miles along the

escarpments exposing the edges of the strata before he became aware of it. It is most noticeable in the Trias, and in the sequel this will be more fully discussed. The explanation of this attenuation of the strata towards the east is as follows.

It is a common fact that the greatest thickness of a group of strata is usually found near the shore-lines of the mainlands from which their materials came. As we recede from these ancient shore-lines we generally find that the strata diminish in thickness, at first quite rapidly, but afterwards more slowly The materials deposited near the shores are, in many cases, of coarser texture than those deposited at a distance from them. This is not always true of every distinct bed, but if we consider any group of strata with many members we shall usually find it true of the group as a whole. In the case of the Mesozoic strata of the terraces, they are remnants of beds deposited in a sea or bay, the shore-line of which lay to the westward and northwestward. The position of this shore-line, no doubt, varied during the Mesozoic periods, now advancing and now receding; but in general terms its mean position appears to have been nearly along what is now the boundary of the Basin Province. The Great Basin was then dry land, undergoing denudation, and its detritus was washed down on this side into the sea, where the Mesozoic strata of the Plateau Province accumulated. The position of this ancient shore-line in the sierra country south of the literal Basin and west of the Grand Cañon district we do not as yet know; the presumed location not being explored as yet. This attenuation of the strata and their relation to the shore-line of the mainland, from which they were in great part at least derived, is another important factor which must be kept in mind in the course of the discussion.

WATERSHEDS OF THE TERRACES.

It will be well to bestow also a glance at the distribution of the more important drainage channels. The western portion of the terrace is drained by the branches of the Virgen River. Upon the Colob heads the northern fork of the Virgen, sometimes called the Mu-kún-tu-weap, sometimes Little

Zion River. It flows due south. East of this is the eastern fork, called the Pa-rú-nu-weap. Both branches have their sources at the base of the Pink Cliffs (Eocene), and at length unite to form the Virgen. Their channels are surely very wonderful freaks of nature. The Parúnuweap, after collecting its several filaments on the slopes of the Cretaceous terrace, at length begins to burrow into the Jurassic, cutting a very deep and remarkably narrow gap in the white sandstone, and then into and through the Trias. For many miles it flows in a mere cleft barely 50 feet wide at the bottom and sometimes narrower, and attaining a depth of more than 2,500 feet. In scouring down its channel into the sandstones the stream did not cut always vertically, but swayed from side to side, so that now great bulges of the wall overhang the bottom of the abyss, and in some places shut out the sky overhead. The Makúntuweap, or Little Zion Fork, is even more remarkable. For a considerable distance this stream also runs in a profound and exceptionally narrow chasm, but it at length widens out, and just where it joins the Parúnuweap is a scene which must ultimately become, when the knowledge of it is spread, one of the most admired in the world. Of this hereafter. Below the junction of the forks the Virgen flows westward, and passes out of the terraces and out of the Plateau Province. At length it joins the Colorado.

East of the drainage area of the Virgen is that of Kanab Creek. It heads in the broad valley of Upper Kanab, which occupies an indentation of the southern margin of the High Plateaus between the Markágunt and Paunságunt. The bulk of the drainage passes through the upper cañon of Kanab Creek, and at length emerges upon the desert to the southward. Further on it sinks another chasm in the Carboniferous, which becomes a mighty side gorge of the Colorado, and unites with the Grand Cañon in the middle of the Kanab division.

Still eastward is the great amphitheater which gives rise to the branches of the Paria. This stream flows southeastward and ultimately enters the Colorado at the head of the Marble Cañon.

In these three subordinate drainage basins of the terraces it is well to notice some features of importance, common more or less to all, but most distinctly seen in Kanab Creek. They all run contrary to the dip of the

strata. The summits of the terraces dip to the northward, while the streams run southward. They thus form each a chain of cañons. Thus, Kanab Creek, with its upper tributaries flowing in open valleys, at length begins to cut into the Jurassic, and its gorge, ever deepening, at length becomes nearly a thousand feet in depth. Suddenly the cañon walls swing to right and left to form the mural front which terminates the Jurassic terrace, and the river, now at the summit of the Trias, is once more in open country; but only for a short distance, for it soon begins to cut into the Trias, forming a great cañon as before. The same process is repeated and the river flows out of its Triassic chasm into the open again, while its walls swing in either direction to form the terminal escarpment of the Triassic terrace.

The three streams just mentioned are not the only drainage channels in the terraces, though they are the principal ones, and sooner or later gather the greater part of the drainage. There are many cañons in the terraces, and they all have the same relation to the cliffs and to the dips of the strata. They cut into the terraces and emerge from them at the bases of their several cliffs. All except the three first mentioned are dry, carrying no streams except spasmodic floods during heavy rains and the melting of the snows. Many of them are actually filling up, the floods being unable to carry away all the sand and clay which the infrequent rains wash into them.

CHAPTER III.

THE VERMILION CLIFFS AND VALLEY OF THE VIRGEN.

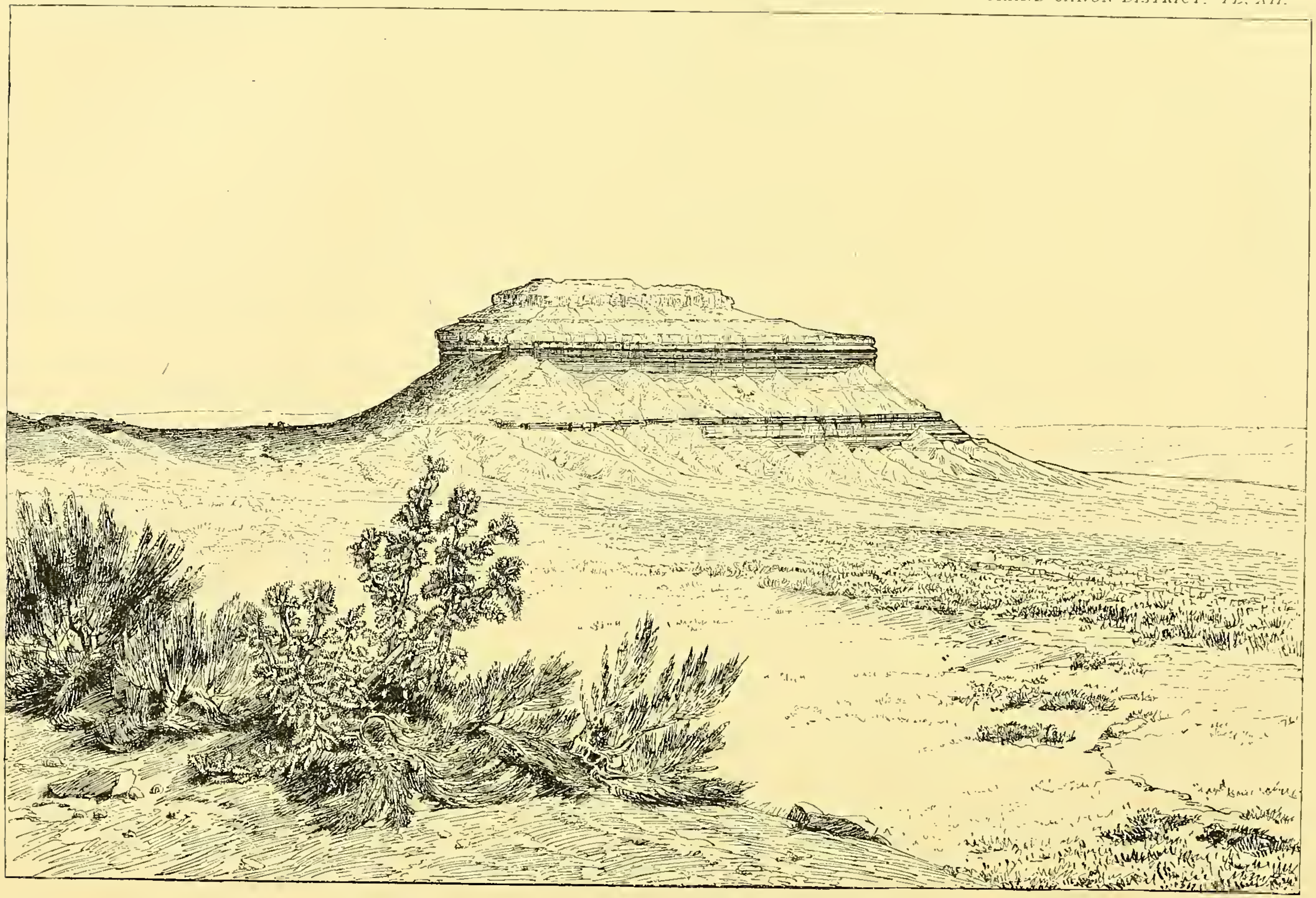
Grandeur and extent of the Vermilion Cliffs.—Their architecture and characteristic profiles.—Increase of their dimensions from Pipe Spring promontory to the Valley of the Virgen.—The great sandstone entablature.—Their buttes.—Towers at Short Creek.—Cloud effects.—Optical delusions.—Smithsonian Butte.—The Temples and Towers of the Virgen.—Little Zion Valley.

To this great wall, terminating the Triassic terrace and stretching from the Hurricane Ledge to the Paria, Powell has given the name of The Vermilion Cliffs. Their great altitude, the remarkable length of their line of frontage, the persistence with which their proportions are sustained throughout the entire interval, their ornate sculpture and rich coloring, might justify very exalted language of description. But to the southward, just where the desert surface dips downward beneath the horizon, are those supreme walls of the Grand Cañon, which we must hereafter behold and vainly strive to describe; and however worthy of admiration the Vermilion Cliffs may be we must be frugal of adjectives, lest in the chapters to be written we find their force and meaning exhausted. They will be weak and vapid enough at best. Yet there are portions of the Vermilion Cliffs which in some respects lay hold of the sensibilities with a force not much less overwhelming than the majesty of the Grand Cañon; not in the same way, not by virtue of the same elements of power and impressiveness, but in a way of their own and by attributes of their own. In mass and grandeur and in the extent of the display there is no comparison; it would be like comparing a private picture gallery containing a few priceless treasures with the wealth of art in the Vatican or Louvre. All of the really superlative portions of the Vermilion Cliffs could be comfortably displayed in any one of half a dozen amphitheaters opening into the Kaibab division of the Grand Cañon.

These portions occur in the beautiful valley of the Virgen, and they, as well as the features which characterize the entire front of the Vermilion Cliffs, merit some attempt at description.

Each of the greater sedimentary groups of the terraces, from the Eocene to the Permian, inclusive, has its own style of sculpture and architecture; and it is at first surprising and always pleasing to observe how strongly the several styles contrast with each other. The elephantine structures of the Nile, the Grecian temples, the pagodas of China, the cathedrals of Western Europe, do not offer stronger contrasts than those we successively encounter as we descend the great stairway which leads down from the High Plateaus. As we pass from one terrace to another the scene is wholly changed; not only in the bolder and grander masses which dominate the landscape, but in every detail and accessory; in the tone of the color-masses, in the vegetation, and in the spirit and subjective influences of the scenery. Of these many and strong antitheses, there is none stronger than that between the repose of the Jura and the animation of the Trias.

The profile of the Vermilion Cliffs is very complex, though conforming to a definite type and made up of simple elements. Though it varies much in different localities it never loses its typical character. It consists of a series of vertical ledges rising tier above tier, story above story, with intervening slopes covered with talus through which the beds project their fretted edges. The stratification is always revealed with perfect distinctness and is even emphasized by the peculiar weathering. The beds are very numerous and mostly of small or moderate thickness, and the partings of the sandstones include layers of gypsum or gypsiferous sand and shale. The weathering attacks these gypseous layers with great effect, dissolving them to a considerable depth into the wall-face, producing a deeply engraved line between the including sandstones. This line is always in deep shadow and throws into strong relief the bright edges of the strata in the rock-face, separating them from each other with uncommon distinctness. Where the profiles are thrown well into view the vertical lines, which bound the faces of the ledges, are quite perpendicular and straight, while the lines of the intervening slopes are feebly concave, being, in fact, descending



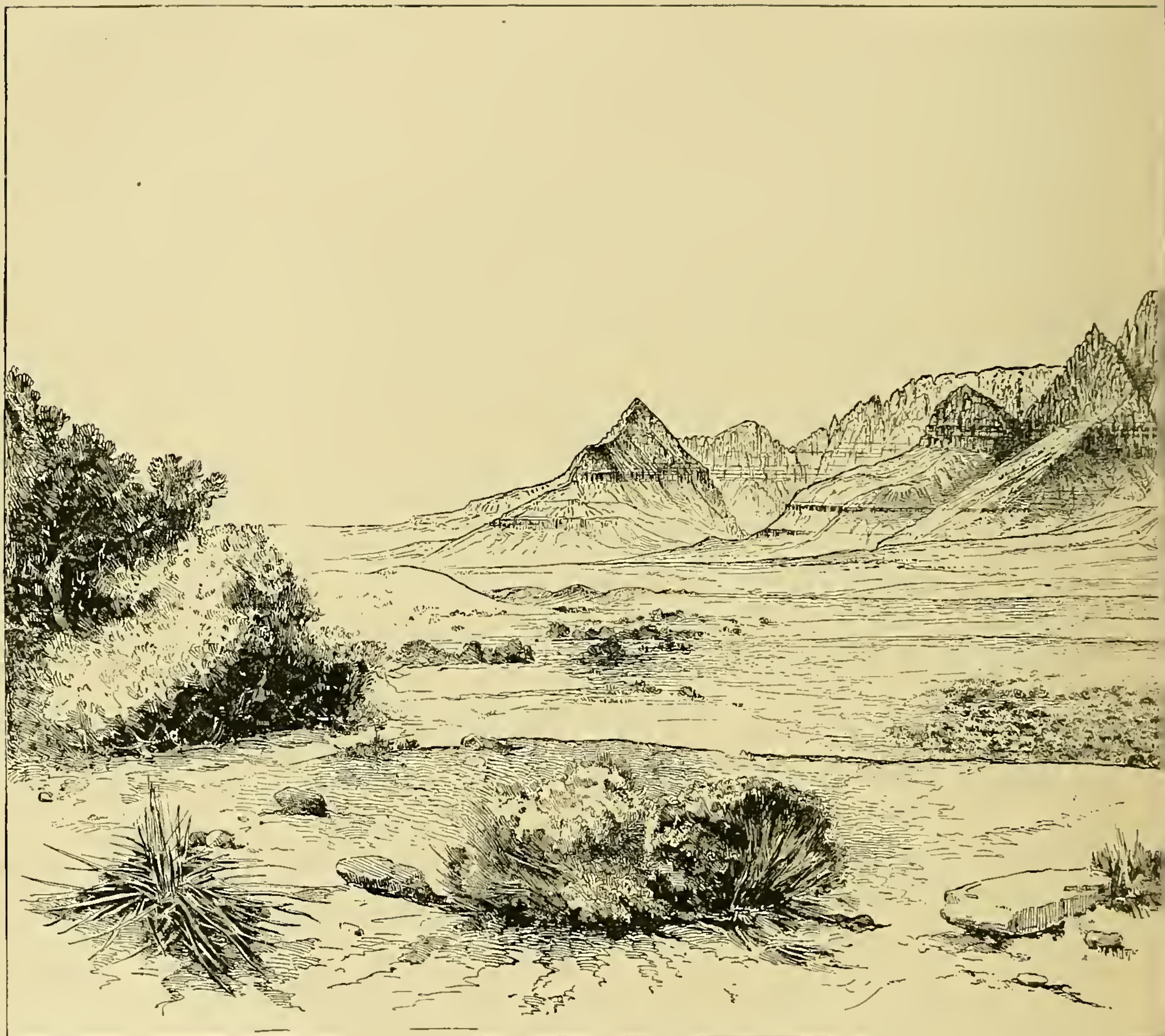
A PERMIAN BUTTE.

branches of hyperbolas. They are graceful in form and indeed genuine lines of beauty. The angles where the straight and curved lines meet, at the bases and summits of the ledges, are very keen and well cut. The composite effect thus given by the multiple cliffs and sloping water-tables rising story above story, by the acute definition of the profiles and horizontal moldings, and by the refined though unobtrusive details, is highly architectural and ornate, and contrasts in the extreme with the rough, craggy, beetling aspect of the cliffs of other regions. This effect is much enhanced by the manner in which the wall advances in promontories or recedes in alcoves, and by the wings and gables with sharp corners and Mansard roofs jutting out from every lateral face where there is the least danger of blankness or monotony. In many places cañons have cut the terrace platform deeply, and open in magnificent gateways upon the broad desert plain in front. We look into them from afar, wonderingly and questioningly, with a fancy pleased to follow their windings until their sudden turns carry them into distant, unseen depths.

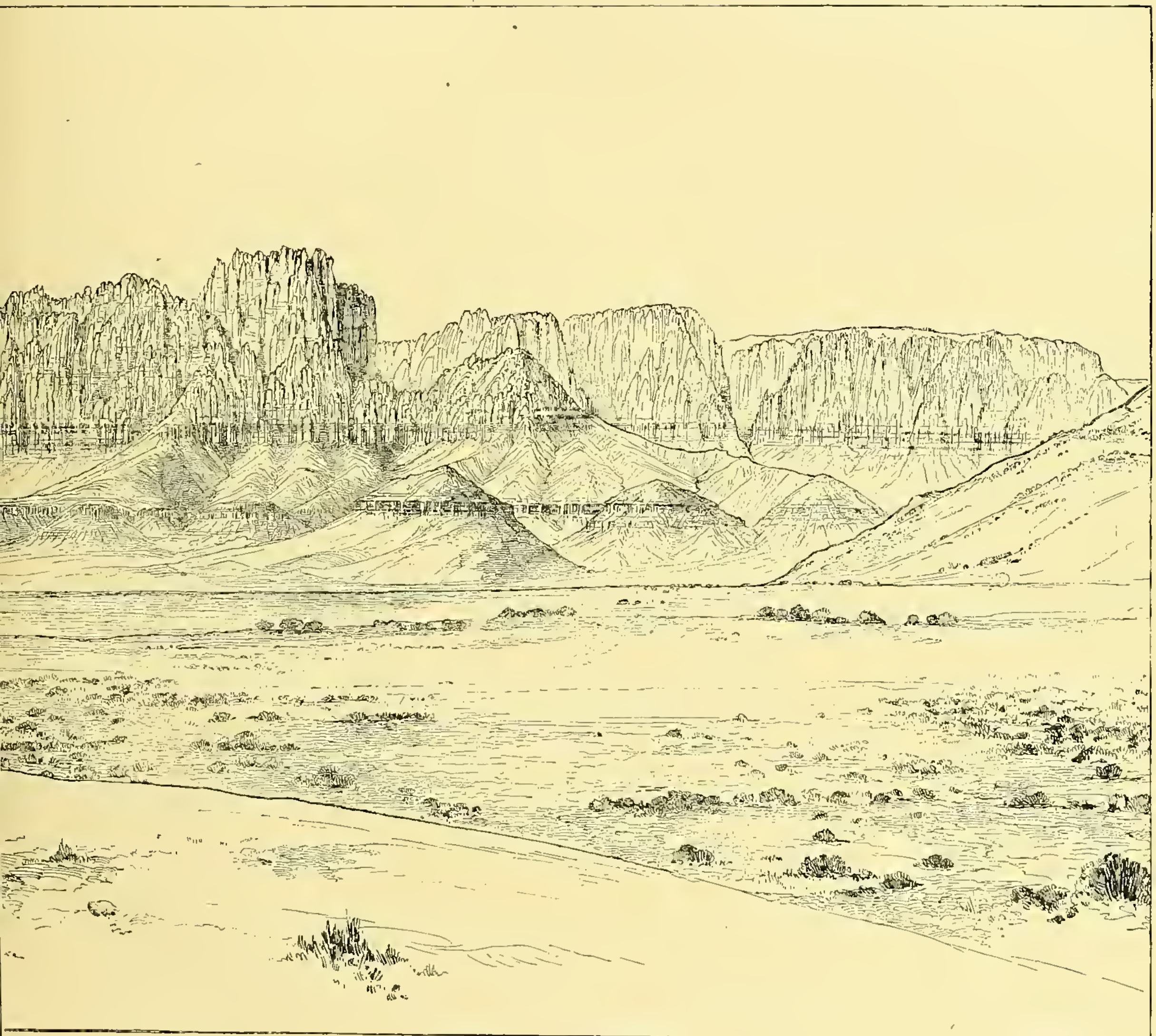
Northwestward of the southernmost promontory at Pipe Spring, the cliffs steadily increase in grandeur and animation, and also assume new features. Near the summit of the series is a very heavy stratum of sandstone, which is everywhere distinguishable from the others. This member is seen at Kanab with a thickness of about 200 feet. It increases westward, becoming 400 feet at Pipe Spring. Beyond that it still increases, reaching a thickness of more than 1,200 feet in the valley of the Virgen It has many strong features, and yet they elude description. One point, however, may be seized upon, and that is a series of joints nearly vertical with which the mass is everywhere riven. The fissures thus produced have been slowly enlarged by weathering, and down the face of every escarpment run the dark shadows of these rifts. They reach often from top to bottom of the mass and penetrate deeply its recesses. Wherever this great member forms the entablature—and west of Pipe Spring it usually does so—its crest is uneven and presents towers and buttresses produced by the widening of these cracks. Near Short Creek it breaks into lofty truncated towers of great beauty and grandeur, with strongly emphasized vertical lines and decorations, suggestive of cathedral architecture on a colossal

scale. Still loftier and more ornate become the structures as we approach the Virgen. At length they reach the sublime. The altitudes increase until they approach 2,000 feet above the plain. The wall is recessed with large amphitheaters, buttressed with huge spurs and decorated with towers and pinnacles. Here, too, for the first time, along their westward trend, the Vermilion Cliffs send off buttes. And giant buttes they verily are, rearing their unassailable summits into the domain of the clouds, rich with the aspiring forms of Gothic type, and flinging back in red and purple the intense sunlight poured over them. Could the imagination blanch those colors, it might compare them with vast icebergs, rent from the front of a glacier and floating majestically out to sea, only here it is the parent mass that recedes, melting away through the ages, while its offspring stands still; yet the analogy would be a feeble one, for the buttes are grander, more definite in form, and many times loftier. But the climax of this scenery is still beyond.

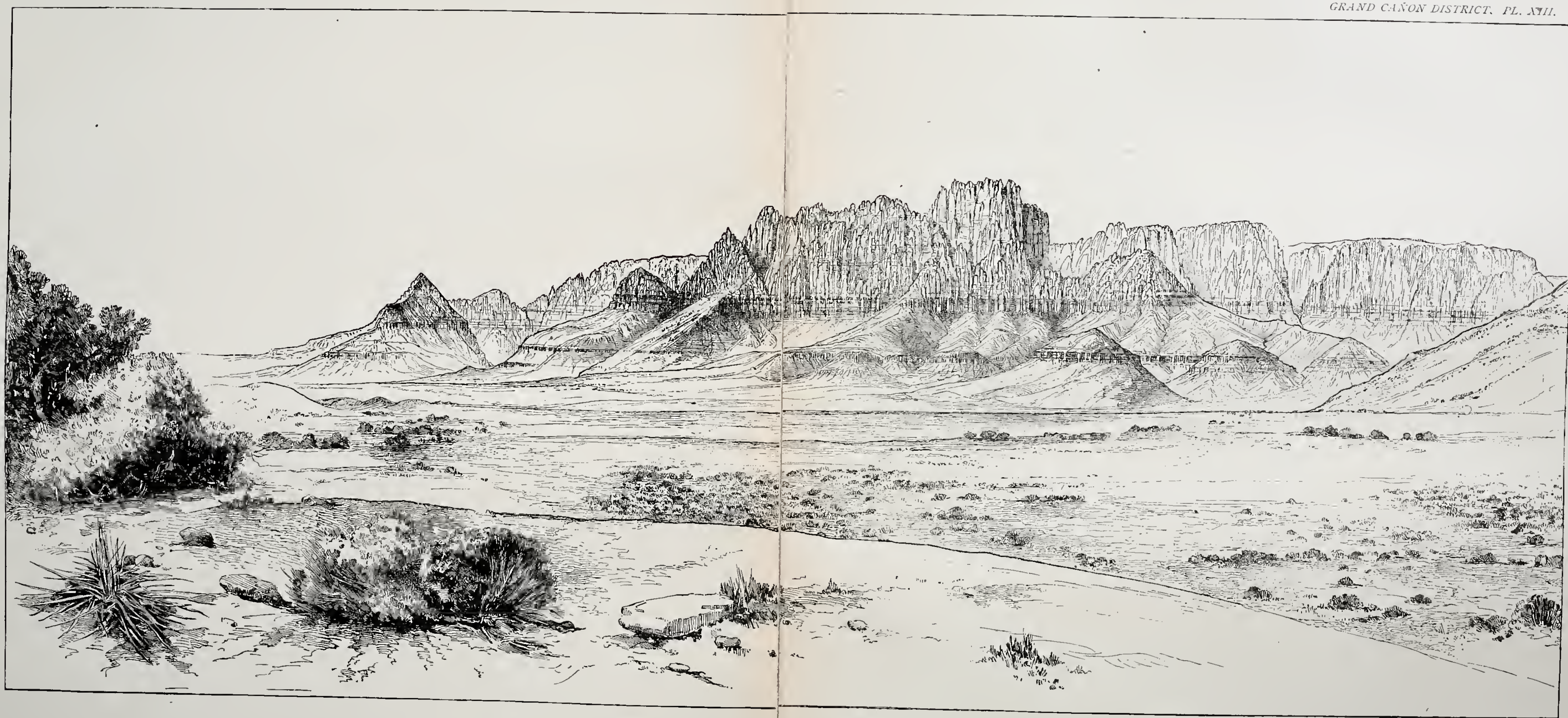
Late in the autumn of 1880 I rode along the base of the Vermilion Cliffs from Kanab to the Virgen, having the esteemed companionship of Mr. Holmes. We had spent the summer and most of the autumn among the cones of the Uinkaret, in the dreamy parks and forests of the Kaibab, and in the solitudes of the intervening desert; and our sensibilities had been somewhat overtasked by the scenery of the Grand Cañon. It seemed to to us that all grandeur and beauty thereafter beheld must be mentally projected against the recollection of those scenes, and be dwarfed into commonplace by the comparison; but as we moved onward the walls increased in altitude, in animation, and in power. At length the towers of Short Creek burst into view, and, beyond, the great cliff in long perspective thrusting out into the desert plain its gables and spurs. The day was a rare one for this region. The mild, subtropical autumn was over, and just giving place to the first approaches of winter. A sullen storm had been gathering from the southwest, and the first rain for many months was falling, mingled with snow. Heavy clouds rolled up against the battlements, spreading their fleeces over turret and crest, and sending down curling flecks of white mist into the nooks and recesses between towers and buttresses. The next day was rarer still, with sunshine and storm battling for



TOWERS OF SHORT CR



[.—VERMILION CLIFFS.



TOWERS OF SHORT CREEK.—VERMILION CLIFFS.

the mastery. Rolling masses of cumuli rose up into the blue to incomprehensible heights, their flanks and summits gleaming with sunlight, their nether surfaces above the desert as flat as a ceiling, and showing, not the dull neutral gray of the east, but a rosy tinge caught from the reflected red of rocks and soil. As they drifted rapidly against the great barrier, the currents from below flung upward to the summits, rolled the vaporous masses into vast whorls, wrapping them around the towers and crest-lines, and scattering torn shreds of mist along the rock-faces. As the day wore on the sunshine gained the advantage. From overhead the cloud-masses stubbornly withdrew, leaving a few broken ranks to maintain a feeble resistance. But far in the northwest, over the Colob, they rallied their black forces for a more desperate struggle, and answered with defiant flashes of lightning the incessant pour of sun-shafts.

Superlative cloud effects, common enough in other countries, are lamentably infrequent here; but, when they do come, their value is beyond measure. During the long, hot summer days, when the sun is high, the phenomenal features of the scenery are robbed of most of their grandeur, and cannot, or do not, wholly reveal to the observer the realities which render them so instructive and interesting. There are few middle tones of light and shade. The effects of foreshortening are excessive, almost beyond belief, and produce the strangest deceptions. Masses which are widely separated seem to be superposed or continuous. Lines and surfaces, which extend towards us at an acute angle with the radius of vision, are warped around until they seem to cross it at a right angle. Grand fronts, which ought to show depth and varying distance, become flat and are troubled with false perspective. Proportions which are full of grace and meaning are distorted and belied. During the midday hours the cliffs seem to wilt and droop as if retracting their grandeur to hide it from the merciless radiance of the sun whose very effulgence flouts them. Even the colors are ruined. The glaring face of the wall, where the light falls full upon it, wears a scorched, overbaked, discharged look; and where the dense black shadows are thrown—for there are no middle shades—the magical haze of the desert shines forth with a weird, metallic glow which has no color in it. But as the sun declines there comes a revival. The half-tones at length

appear, bringing into relief the component masses; the amphitheaters recede into suggestive distances; the salients silently advance towards us; the distorted lines range themselves into true perspective; the deformed curves come back to their proper sweep; the angles grow clean and sharp; and the whole cliff arouses from lethargy and erects itself in grandeur and power as if conscious of its own majesty. Back also come the colors, and as the sun is about to sink they glow with an intense orange vermilion that seems to be an intrinsic luster emanating from the rocks themselves. But the great gala-days of the cliffs are those when sunshine and storm are waging an even battle; when the massive banks of clouds send their white diffuse light into the dark places and tone down the intense glare of the direct rays; when they roll over the summits in stately procession, wrapping them in vapor and revealing cloud-girt masses here and there through wide rifts. Then the truth appears and all deceptions are exposed. Their real grandeur, their true forms, and a just sense of their relations are at last fairly presented, so that the mind can grasp them. And they are very grand—even sublime. There is no need, as we look upon them, of fancy to heighten the picture, nor of metaphor to present it. The simple truth is quite enough. I never before had a realizing sense of a cliff 1,800 to 2,000 feet high. I think I have a definite and abiding one at present.

As we moved northward from Short Creek, we had frequent opportunities to admire these cliffs and buttes, with the conviction that they were revealed to us in their real magnitudes and in their true relations. They awakened an enthusiasm more vivid than we had anticipated, and one which the recollection of far grander scenes did not dispel. At length the trail descended into a shallow basin where a low ledge of sandstones, immediately upon the right, shut them out from view; but as we mounted the opposite rim a new scene, grander and more beautiful than before, suddenly broke upon us. The cliff again appeared, presenting the heavy sandstone member in a sheer wall nearly a thousand feet high, with a steep talus beneath it of eleven or twelve hundred feet more. Wide alcoves receded far back into the mass, and in their depths the clouds floated. Long, sharp spurs plunged swiftly down, thrusting their monstrous buttresses into the plain below, and sending up pinnacles and towers along the knife edges.

THE EASTERN TEMPLE.

But the controlling object was a great butte which sprang into view immediately before us, and which the salient of the wall had hitherto masked. Upon a pedestal two miles long and 1,000 feet high, richly decorated with horizontal moldings, rose four towers highly suggestive of cathedral architecture. Their altitude above the plain was estimated at about 1,800 feet. They were separated by vertical clefts made by the enlargement of the joints, and many smaller clefts extending from the summits to the pedestal carved the turrets into tapering buttresses, which gave a graceful aspiring effect with a remarkable definiteness to the forms. We named it Smithsonian Butte, and it was decided that a sketch should be made of it; but in a few moments the plan was abandoned or forgotten. For over a notch or saddle formed by a low isthmus which connected the butte with the principal mesa there sailed slowly and majestically into view, as we rode along, a wonderful object. Deeply moved, we paused a moment to contemplate it, and then abandoning the trail we rode rapidly towards the notch, beyond which it soon sank out of sight. In an hour's time we reached the crest of the isthmus, and in an instant there flashed before us a scene never to be forgotten. In coming time it will, I believe, take rank with a very small number of spectacles each of which will, in its own way, be regarded as the most exquisite of its kind which the world discloses. The scene before us was

THE TEMPLES AND TOWERS OF THE VIRGEN.

At our feet the surface drops down by cliff and talus 1,200 feet upon a broad and rugged plan cut by narrow cañons. The slopes, the winding ledges, the bosses of projecting rock, the naked, scanty soil, display colors which are truly amazing. Chocolate, maroon, purple, lavender, magenta, with broad bands of toned white, are laid in horizontal belts, strongly contrasting with each other, and the ever-varying slope of the surface cuts across them capriciously, so that the sharply defined belts wind about like the contours of a map From right to left across the further foreground of the picture stretches the inner cañon of the Virgen, about

700 feet in depth, and here of considerable width. Its bottom is for the most part unseen, but in one place is disclosed by a turn in its course, showing the vivid green of vegetation. Across the cañon, and rather more than a mile and a half beyond it, stands the central and commanding object of the picture, the western temple, rising 4,000 feet above the river. Its glorious summit was the object we had seen an hour before, and now the matchless beauty and majesty of its vast mass is all before us. Yet it is only the central object of a mighty throng of structures wrought up to the same exalted style, and filling up the entire panorama. Right opposite us are the two principal forks of the Virgen, the Parúnuweap coming from the right or east, and the Mukúntuweap or Little Zion Valley, descending towards us from the north. The Parúnuweap is seen emerging on the extreme right through a stupendous gateway and chasm in the Triassic terrace, nearly 3,000 feet in depth. The further wall of this cañon, at the opening of the gateway, quickly swings northward at a right angle and becomes the eastern wall of Little Zion Valley. As it sweeps down the Parúnuweap it breaks into great pediments, covered all over with the richest carving. The effect is much like that which the architect of the Milan Cathedral appears to have designed, though here it is vividly suggested rather than fully realized—as an artist painting in the "broad style" suggests many things without actually drawing them. The sumptuous, bewildering, mazy effect is all there, but when we attempt to analyze it in detail it eludes us. The flank of the wall receding up the Mukúntuweap is for a mile or two similarly decorated, but soon breaks into new forms much more impressive and wonderful. A row of towers half a mile high is quarried out of the palisade, and stands well advanced from its face. There is an eloquence to their forms which stirs the imagination with a singular power, and kindles in the mind of the dullest observer a glowing response. Just behind them, rising a thousand feet higher, is the eastern temple, crowned with a cylindric dome of white sandstone; but since it is, in many respects, a repetition of the nearer western temple, we may turn our attention to the latter. Directly in front of us a complex group of white towers, springing from a central pile, mounts upwards to the clouds. Out of their midst, and high over all, rises a dome-like mass, which dominates the entire land-

THE WESTERN TEMPLE.

scape. It is almost pure white, with brilliant streaks of carmine descending its vertical walls. At the summit it is truncated, and a flat tablet is laid upon the top, showing its edge of deep red. It is impossible to liken this object to any familiar shape, for it resembles none. Yet its shape is far from being indefinite; on the contrary, it has a definiteness and individuality which extort an exclamation of surprise when first beheld. There is no name provided for such an object, nor is it worth while to invent one. Call it a dome; not because it has the ordinary shape of such a structure, but because it performs the function of a dome.

The towers which surround it are of inferior mass and altitude, but each of them is a study of fine form and architectural effect. They are white above, and change to a strong, rich red below. Dome and towers are planted upon a substructure no less admirable. Its plan is indefinite, but its profiles are perfectly systematic. A curtain wall 1,400 feet high descends vertically from the eaves of the temples and is succeeded by a steep slope of ever-widening base courses leading down to the esplanade below. The curtain-wall is decorated with a lavish display of vertical moldings, and the ridges, eaves, and mitered angles are fretted with serrated cusps. This ornamentation is suggestive rather than precise, but it is none the less effective. It is repetitive, not symmetrical. But though exact symmetry is wanting, nature has here brought home to us the truth that symmetry is only one of an infinite range of devices by which beauty can be materialized.

> And finer forms are in the quarry
> Than ever Angelo evoked.

Reverting to the twin temple across Little Zion Valley, its upper mass is a repetition of the one which crowns the western pile. It has the same elliptical contour, and a similar red tablet above. In its effect upon the imagination it is much the same. But from the point from which we first viewed them—and it is by far the best one accessible—it was too distant to be seen to the fullest advantage, and the western temple by its greater proximity overpowered its neighbor.

Nothing can exceed the wondrous beauty of Little Zion Valley, which separates the two temples and their respective groups of towers. Nor are these the only sublime structures which look down into its depths, for simi-

lar ones are seen on either hand along its receding vista until a turn in the course carries the valley out of sight. In its proportions it is about equal to Yo Semite, but in the nobility and beauty of the sculptures there is no comparison. It is Hyperion to a satyr. No wonder the fierce Mormon zealot, who named it, was reminded of the Great Zion, on which his fervid thoughts were bent—"of houses not built with hands, eternal in the heavens."

From those highly wrought groups in the center of the picture the eye escapes to the westward along a mass of cliffs and buttes covered with the same profuse decoration as the walls of the temples and of the Parúnuweap. Their color is brilliant red. Much animation is imparted to this part of the scene by the wandering courses of the mural fronts which have little continuity and no definite trend. The Triassic terrace out of which they have been carved is cut into by broad amphitheaters and slashed in all directions by wide cañon valleys. The resulting escarpments stretch their courses in every direction, here fronting towards us, there averted; now receding behind a nearer mass, and again emerging from an unseen alcove. Far to the westward, twenty miles away, is seen the last palisade lifting its imposing front behind a mass of towers and domes to an altitude of probably near 3,000 feet and with a grandeur which the distance cannot dispel. Beyond it the scenery changes almost instantly, for it passes at once into the Great Basin, which, to this region, is as another world.

CHAPTER IV.

THE GREAT DENUDATION.

The great lesson of the terraces is erosion.—Its amount stated.—The amount though very great is not abnormal.—Erosion and deposition are complementary processes.—Methods of erosion by recession of cliffs.—Examination of the evidences of the erosion.—Argument from the stratification. Argument from the displacements.—Argument from the drainage system.—Base levels of erosion.

Before leaving the terraces we may with advantage pause to contemplate the great lesson which they lay open to us. The subject of the lesson is Erosion. The geologist, seeing that around a considerable part of the periphery of the Grand Cañon district the Eocene and Mesozoic strata suddenly terminate in great cliffs facing the Carboniferous platform, would at once conclude that these strata formerly reached beyond their present boundaries. But how far? The answer may be proposed at once. They extended over the entire Grand Cañon district and reached into central Arizona, where they ended along the shore of an ancient mainland, from which their materials were in part derived. The distance of that shore-line from the summit of the Pink Cliffs is from 130 to 180 miles, and the width of the denuded district is from 120 to 140 miles. From the base of the Vermilion Cliffs the distance is from 25 to 30 miles less. The area of maximum denudation is from 13,000 to 15,000 square miles, and the average thickness of the strata removed from it was about 10,000 feet.

The general reader will no doubt feel a strong aversion to such prodigious figures, and even the geologist may hesitate. In order that the reader may not be obliged to carry a heavy burden of prejudice as he follows the various steps of the argument, it is well to anticipate some part of the discussion and thus relieve him of a great part of the load at the outset; for it can be shown that the figures, while they are certainly very large, are in no respect abnormal and in only one respect are they at all unusual.

Erosion viewed in one way is the supplement of the process by which strata are accumulated. The materials which constitute the stratified rocks were derived from the degradation of the land. This proposition is fundamental in geology—nay, it is the broadest and most comprehensive proposition with which that science deals. It is to geology what the law of gravitation is to astronomy. We can conceive no other origin for the materials of the strata, and no other is needed, for this one is sufficient and its verity a thousand times proven. Erosion and "sedimentation" are the two half phases of one cycle of causation—the debit and credit sides of one system of transactions. The quantity of material which the agents of erosion deal with is in the long run exactly the same as the quantity dealt with by the agencies of deposition; or, rather, the materials thus spoken of are one and the same. If, then, we would know how great have been the quantities of material removed in any given geological age from the land by erosion, we have only to estimate the mass of the strata deposited in that age. Constrained by this reasoning the mind has no escape from the conclusion that the effects of erosion have indeed been vast. If then these operations have achieved such results, our wonder is transferred to the immensity of the periods of time required to accomplish them; for the processes are so slow that the span of a life-time seems too small to render those results directly visible. As we stand before the terrace cliffs and try to conceive of them receding scores of miles by secular waste, we find the endeavor quite useless. There is, however, one error against which we must guard ourselves. We must not conceive of erosion as merely sapping the face of a straight serried wall a hundred miles long; the locus of the wall receding parallel to its former position at the rate of a foot or a few feet in a thousand years; the terrace back of its crest line remaining solid and uncut; the beds thus dissolving edgewise until after the lapse of millions of centuries their terminal cliffs stand a hundred miles or more back of their initial positions. The true story is told by the Triassic terrace ending in the Vermilion Cliffs. This terrace is literally sawed to pieces with cañons. There are dozens of these chasms opening at intervals of two or three miles along the front of the escarpment and setting far back into its mass. Every one of them ramifies again and again until they become an intricate net-work, like the fibers of

a leaf. Every cañon wall, throughout its trunk, branches, and twigs, and every alcove and niche, becomes a dissolving face. Thus the lines and area of attack are enormously multiplied. The front wall of the terrace is cut into promontories and bays. The interlacing of branch cañons back of the wall cuts off the promontories into detached buttes, and the buttes, attacked on all sides, molder away. The rate of recession, therefore, is correspondingly accelerated in its total effect.

The largeness of the area presents really no difficulty. The forces which break up the rocks are of meteoric origin. The agency which carries off the débris is the water running in the drainage channels. Surely the meteoric forces which ravage the rocks of a township may ravage equally the rocks of the county or state, provided only the conditions are uniform over the larger and smaller areas. And what is the limit to the length of a stream, the number of its branches and rills, and to the quantity of water it may carry? It is not the area, then, which oppresses us by its magnitude, but the vertical factor—the thickness of the mass removed. But upon closer inspection the aspect of this factor also will cease to be forbidding.

For if the rate of recession of a wall fifty feet high is one foot in a given number of years, what will be (*ceteris paribus*) the rate of recession in a wall a thousand feet high? Very plainly the rate will be the same.* If we suppose two walls of equal length, composed of the same kind of rocks, and situated under the same climate, but one of them twice as high as the other, it is obvious that the areas of wall-face will be proportional to their altitudes. In order that the rates of recession may be equal, the amount of material removed from the higher one must be double that removed from the other, and since the forces operating on the higher one have twice the area of attack, they ought to remove from it a double quantity, thus making the rates of recession equal. In the same way it may be shown that the

* The geologist will no doubt recognize that this is a simple and unqualified statement of a result which is in reality very complex, and sometimes requiring qualification. But a candid review of it in the light of established laws governing erosion will, I am confident, justify it for all purposes here contemplated. Though some qualifying conditions will appear when the subject is analyzed thoroughly, they are of no application to this particular stage of the argument. The statement is amply true for the proposition in hand, and it would be hardly practicable, and certainly very prolix, to give here the full analysis of it.

rate of recession is substantially independent of the magnitude of the cliff, whatever its altitude. Here a momentary digression is necessary.

We have hitherto spoken of the recession of the cliffs as if it comprised the whole process of erosion, and have hardly alluded to the possible degradation of the flat surfaces of plateaus, terraces, and plains. Is it meant that there is no degradation of the horizontal surfaces, and that the waste of the land is wholly wrought by the decay of cliffs? Approximately that is the meaning, but some greater precision may be given to the statement.

Erosion is the result of two complex groups of processes. The first group comprises those which accomplish the disintegration of the rocks, reducing them to fragments, pebbles, sand, and clay. The second comprises those processes which remove the débris and carry it away to another part of the world. The first is called disintegration; the second, transportation. We need not attempt to study these processes in all their scope and relations, but we may advert only to those considerations which are of immediate concern. When the débris produced by the disintegration of rocks is left to accumulate upon a flat surface it forms a protecting mantle to the rocks beneath, and the disintegration is greatly retarded, or even wholly stopped. In order that disintegration may go on rapidly the débris must be carried away as rapidly as it forms. But the efficiency of transportation depends upon the declivity. The greater the slope the greater the power of water to transport. When the slope is greater than 30° to 33° (the angle of repose), loose matter cannot lie upon the rocks, and shoots down until it finds a resting place. Hence the greater the slope the more fully are the rocks exposed to the disintegrating forces, and the more rapidly do they decay. This relation is universal, applying to all countries, and explains how it comes about that the attack of erosion is highly effective against the cliffs and steep slopes, and has but a trifling effect upon flat surfaces.

Reverting to the main argument, it now appears that erosion goes on by the decay and removal of material from cliffs and slopes; that the recession of high cliffs is as rapid as the recession of low ones, and that the quantity of material removed in a given time increases with the altitudes of the cliffs and slopes. In other words, the thickness of the strata removed in a given

period of erosion should be proportional to the amount of *relief* in the profiles of the country. But in the Plateau Country, and especially in the Grand Cañon district, these reliefs are very great. It is a region of giant cliffs and profound cañons, and, as will ultimately appear, it has been so during a very long stretch of geological time. The thickness of the strata removed from it is only proportional to the values of those conditions which favor rapid erosion. In the foregoing discussion it may appear that the area of denudation in the Grand Cañon district, though large, and the thickness of the strata denuded, though very great, are not so excessive as to impose such a heavy burden upon the credulity as the first announcement of the figures portended.

We may now proceed to examine the evidence upon which the inference of so great a denudation is founded. In this discussion three classes of facts will be utilized: 1st, the stratification; 2d, the displacements; 3d, the drainage. Each, by itself alone considered, might be deemed insufficient; but when they are all placed in their natural relations to each other, they form a compact and self-consistent whole which is quite convincing.

I. In drawing inferences from the stratification, the geologist is obviously bound to presume that the beds cut off in the terraces, and in the long line of the Echo Cliffs, extended originally without a break, until they reached some locality where the conditions of deposition failed. There are two, and only two, cases to be considered. The first case is that in which the extension is towards the shore-line of the sea in which the strata were deposited. At the shore-line of course the strata ended. The second case involves their extension away from shore-lines, in which event they thin out seaward, and either vanish entirely or dwindle to a merely nominal volume. It becomes essential therefore to ascertain something about the situations of the shore-lines of the sea in which the Mesozoic strata were deposited.

In the preceding chapter I have frequently alluded to the littoral belt of strata situated in southwestern Utah and Nevada. These strata are the continuations of those which form the terraces and the entire sedimentary masses of the High Plateaus. In Mesozoic time the Great Basin area of Nevada and western Utah was a large mainland, and the littoral belt

referred to lies along a portion of its southeastern shore. Great masses of Triassic and Jurassic beds are turned up along this belt with every indication of a shore-line: conglomerates, coarse sandstones, and grits, much faulted and flexed, and showing those peculiar unconformities produced by the sinking and flexing of overloaded littoral beds, as the coarse detritus is rapidly piled up. Beyond is the greatly ravaged platform of Archæan and Paleozoic rocks. It has been shown in the preceding chapter that these formations and indeed the entire Mesozoic slowly attenuate as they recede eastward and east-southeast from this shore line. The extension of the shore of the Mesozoic mainland towards the west or southwest remains to be sought. It has never yet been explored. But another portion of the coast of the Mesozoic sea important for our purposes may be pointed out.

Starting from the base of the Vermilion Cliffs and proceeding southward to the Grand Cañon, we find no traces of a shore-line. If any more recent than Carboniferous time had existed in the interval, it would have left vestiges, and these vestiges could not have escaped our observation. In the extension of the formations of the terraces, therefore, we find no logical halting place north of the Grand Cañon. In all the interval the conditions of the problem are quite unchanged. The logic which extends them a half mile extends them to the brink of the chasm. But even here the problem persists. The mind leaps across the abyss only to find the object of its pursuit receding ever southward. At the San Francisco Mountains the pursuit is not ended. Here are several Ætnas surrounded by a host of young craters which have deluged the country with rhyolite and basalt, hiding the strata beneath. Beyond these Phlegraean fields the Carboniferous beds reappear as before, stretching away southward and sensibly horizontal until at last they come to a sudden end in the Aubrey Cliffs. These cliffs face southward and southwestward, overlooking a region of totally different character from that of the Plateau Province. It is a sierra country quite similar to the Great Basin. It discloses a rugged platform of Archaean rocks, here preserving a few old rags of lower Carboniferous strata, there covered with cumbrous masses of rhyolite and irregular slops of basalt. It is bent, warped, shattered, faulted, and flexed; with short misshapen

ridges of granite, gneiss, and schist, traversing it at narrow intervals, and with their axes trending northwest and southeast.

Here at last is the logical halting place. The sierra country beyond the Aubrey Cliffs was a mainland in Mesozoic time just like the Great Basin, and sent down its detritus into the Mesozoic sea, which washed its coast and stretched away eastward to join the Mesozoic ocean, which submerged the central portions of the North American continent. The Arizona coast trended northwestward. The Great Basin coast trended southwestward, and the two, if sufficiently prolonged, would meet somewhere in Southern Nevada. But of the localities near this imaginary junction we know almost nothing geologically.

Reverting now to the distribution of the Mesozoic strata around the borders of the Grand Cañon district, as explained in the preceding chapters, we find that they occupy the entire northern side and the entire eastern side and appear for a short distance upon the western side. The remaining portion of the periphery of the district is in greatest part and perhaps wholly a shore-line. Whatsoever extensions we assign to the edges of the Mesozoic, whether in the terraces or in the Echo Cliffs, are towards the original coast of the sea in which they were deposited; and since we can find no reason for terminating them until we reach that coast, we seem compelled to infer that they once covered the entire district.

The second case would raise the question whether these beds may not have thinned out to a merely nominal volume or vanished entirely in their extensions over the denuded area. The answer to this is strongly adverse. We have just noted that these extensions are towards the shore and not away from it, while the directions in which strata attenuate are usually the reverse. Towards the coasts they thicken. We have already noted how the strata in the terraces decrease in volume towards the east and southeast, and as we travel along the Paria Plateau and the foot of the Echo Cliffs, we find that they have reached a minimum. But all this I have allowed for in estimating the average denudation of the Grand Cañon platform. If they are below the average volume in the Echo Cliffs, they are quite as much above it in the Valley of the Virgen. In connection with the possible variations in the thickness it may be remarked that one of the most

striking characteristics of the strata of the Plateau Country is the remarkable constancy of the character of each formation over vast expanses of country, and the extreme slowness with which their thickness varies from point to point.

It still remains to inquire whether we are to assume this extension for the entire Mesozoic system, together with the Permian below and the Eocene above, or if it applies only to the older of these formations; for instance, the Permian and Trias. It may be replied that while the presumption is very strong in favor of the whole the weight of evidence varies with the different formations. In the case of the Permian it is conclusive. Innumerable remnants of this formation are scattered over the Carboniferous platform, and the eye and mind carry the connection easily from one remnant to the other. In the Trias the outlying remnants are very few, yet these few are situated in such a manner that they leave no reasonable doubt; and the Trias carries the Jura with it. The two formations are so nearly co-extensive, and are so intimately associated that the very small difference in the distribution of their masses now remaining will not appreciably affect the conclusions to be drawn. So, too, of the Cretaceous. This series is wanting from some Triassic areas, but we should naturally expect the higher formation to be more eroded. No geologist would hesitate to restore it to those areas where the Trias is found, and yet when this is done it is impossible to see how the question of its further extension would differ from that of the Trias.

The Eocene presents undeniably a somewhat greater difficulty; greater, however, in degree and not different in kind. This formation is found only on the northern side of the district and in the littoral belt. It is unknown in the great mesas which are bounded westward by the Echo Cliffs. We find it again only in New Mexico. But the wonder is, not that the Eocene is wanting from such vast areas, if it was deposited over them, but rather that so much of it remains. Still the main argument which has been applied to the other formations holds good when applied to this one. We cannot find any reason for terminating its former extension short of the ancient shore-line in Arizona; but the additional argument from outlying remnants is no doubt weaker. It seems best, therefore, to regard

the full extension of the Eocene as having a very high degree of probability, but falling short of certainty.

II. The foregoing argument is strongly sustained and supplemented by the displacements. If it be true that the Grand Cañon district received between the close of the Carboniferous and the close of the local Eocene 10,000 feet of deposits averaged over its entire surface, it follows that at the latter epoch the summit of the Carboniferous lay at least 10,000 feet below sea-level and was much more nearly horizontal than it is at present. And if such was its position and configuration, the great faults and displacements which traverse it must be of Tertiary age, and there must have been an enormous amount of uplifting, ranging from 12,000 to 18,000 feet, in various portions of the district. These are some of the consequences of the great denudation. If by independent evidence they shall appear to be true—to have really happened—the original inference will be much strengthened; but if they fail, the original inference will be greatly damaged, if not exploded. For it may be remarked that every true deduction runs off into important consequences, and (in geological reasoning, at all events) derives its strongest support from its congruity with a vast system of facts. We shall soon find by independent evidence that the inference of the great denudation agrees rigorously with the above mentioned consequences.

It is first necessary to find the configuration and position of the sea-bottom on which the Mesozoic sediments were deposited at each and every epoch of that age. This problem looks very large and formidable, but an approximate solution is right at hand. During the entire age the surface of deposition was always very near the sea-level. The proof of this is abundant and clear. Throughout the entire Plateau Province the strata are all shallow water deposits. Fossil forests, ripple-marked shales, frequent unconformities by erosion without discrepancy of dip, cross-bedded sandstones, occasional retirements of the waters, all mark very shallow water in the Permian, Trias, and Jura; while coal, carbonaceous shales, abundant remains of land plants indicate the same for the Cretaceous. And, finally, the absence of all traces of appreciable displacement except along the coasts combines to prove that the Mesozoic beds were deposited

with almost rigorous horizontality, and very nearly at sea-level, throughout the entire Mesozoic. This gives us at once a datum horizon of the best possible kind to which all subsequent displacements may be referred.

Its advantage is at once apparent; for it will soon appear very clearly that the faults are all of Tertiary age. In estimating the entire displacement or differential movement involved in a fault, the following difficulty arises. We are often at a loss to ascertain whether one side of the fault plane has been lifted or the other depressed, or even whether both sides may not have been uplifted or lowered, but one of them more than the other; the fault being merely the difference of two movements. But the moment we establish the origin of movement at any datum level, this problem for any particular fault is solved at once. The faults of the Grand Cañon district are those which are due to the differences of upward movement on both sides of the fault planes. This statement is true in every instance, and is fully demonstrated.

The next step is to find the amount and distribution of that part of the movement which is represented by the faults. This is done by depressing the upthrows until the edges of the faulted beds come together and the monoclines are smoothed out. If this be done, the sharp ledges and abrupt breaks in the topography produced by those displacements disappear. The final step is a little more difficult and complex, and it is necessary to describe at some length one important feature of the district.

If we examine the profile of the district from the Markágunt southward to the Grand Cañon, and thence to the Aubrey Cliffs, we shall find that the strata all dip very slightly to the north. The amount of this dip is irregular in different parts of the profile, being for very short distances, and, in a few cases, as much as two and a half or even three degrees; while there are long distances where the strata are strictly horizontal. On an average it is not far from forty minutes. But since its effect is cumulative over the entire distance of 130 to 180 miles, its importance is very great, for the Carboniferous beneath the Markágunt lies below sea-level, while at the San Francisco Mountains it is nearly 8,000 feet above. The dips are strongest near the terraces, and it is very interesting to note the fact that at

the base of each terrace cliff the inclination becomes a maximum.* This prolonged downward tilt towards the north must be borne in mind always in the attempted restoration of the platform to its original condition.

Resuming the reconstruction, we begin at the Markágunt Plateau. Here we find brackish and fresh water beds of Eocene age between 10,000 and 11,000 feet above the sea. To find their position at the beginning of Tertiary time we must in imagination depress them that amount. This carries down the Carboniferous nearly 12,000 feet below sea level. The same treatment is applicable to the entire front of the terraces as far as the Kaiparowits and indefinitely beyond. So also along the line of the Echo Cliffs as far south as our knowledge extends, with, however, a notably diminished amount in that direction arising from the smaller thickness of the Mesozoic strata. Turning to the littoral belt in the Pine Valley Mountains we must depress the country between 4,000 and 6,000 feet, but in a very irregular way, because this region is greatly disturbed. We must also carry on this treatment southward along the Grand Wash and Virgen Range (Atlas Sheet II) as far as the Colorado. Reducing the Grand Wash fault in conjunction with this imaginary depression we find that the Carboniferous at the mouth of the Grand Cañon goes 10,000 feet below the sea. The entire western edge of the Sheavwits goes with it. Along the Echo Cliffs the depression of the same horizon would be 7,500 feet below the sea, and would carry with it the Marble Cañon platform, by the reduction of the Echo Cliff monocline.

Thus around the greater part of the periphery of the district the reconstruction depresses the Carboniferous 7,500 to 12,000 feet below the sea. That the whole Grand Cañon platform follows it seems incontestable. Any other reconstruction would force upon us some unknown arbitrary configuration of the Carboniferous strata for which there is no evidence. It is inadmissible to suppose that flexures, faults, or broad distortions once existed there which have subsequently been smoothed out or reset without leaving a single visible sign; and any other reconstruction than the one here adopted would, it appears to me, involve just such assumptions. And they could

*I cannot refrain from suggesting that this may be due to the gross weight of the terraces themselves. It seems analogous to the action of creeping in deep mines. The inferior beds might have risen higher, were it not for the sudden intervention of these heavy masses of the terrace platforms.

instantly be attacked by considerations arising from the evolution of the drainage system.

It appears, then, that the Grand Cañon district has undergone an enormous amount of upheaval during Tertiary time. The minimum is nearly 12,000 feet and the maximum is about 18,000 feet. The present altitudes of the different portions of its surface mark the difference between the amount of uplift and the depth of denudation. In these respects the region presents quantities above the average of the western half of the United States and which are surpassed only by the great mountain platforms. The inference of a great denudation might be traced to remoter consequences, and so far as I am able to do so I find indications of agreement with such facts as we know; but knowledge becomes imperfect.

III. The evolution of the drainage system of the region is a subject abounding in facts and inferences which group themselves most harmoniously with those already discussed. The origin of rivers has hitherto received too little attention from geologists, apparently because of the intrinsic difficulty which the subject offers in most regions. But it seems as if much more use could be made of it than has hitherto been done even in regions where there is more or less obscurity. There are certain propositions regarding them which may read like truisms, yet which become extremely useful when followed out to their obvious consequences. The self-evident assertion that a river had a beginning implies a great deal. It implies that it originated and developed under the limitations of natural laws, and these laws we know. We are tempted to laugh at the assertion that water does not run up-hill. Yet it would be easy to point out many cases where vexed questions would have been solved if geologists had not forgotten it.

In former writings I have laid stress upon propositions like the following: that the great rivers of a country are as a rule born with the country itself; that their courses were determined by the conditions prevailing at the time of their origin; that their positions once established are (with certain qualifications) immutable. From these propositions flow consequences of great importance. Thus when we find rivers flowing across or through mountain chains and plateaus we must infer that they are older than the

structural deformations which they traverse; that the elevation of a platform across the track of a river rarely diverts it from its course, for the stream saws its bed into the rocks as fast as the obstacle rises. It would be impossible to point out a more complete illustration of these propositions than that which is supplied by the Colorado and its tributaries.

We know that during the whole of Mesozoic time the watershed of the Colorado was submerged and that in Eocene time it was a great fresh-water lake. In due time this lake was drained presumably by the cutting down of its outlet as the country rose. In this process may be discerned the origin of its drainage system; and we are bound to infer that every river then existing within it ran in conformity with the surface just exposed above the waters. To-day we find that surface greatly deformed by displacements and by erosion, and the courses of the rivers to be such as they could not have been if these inequalities and deformations were as old as the rivers. It would be an endless task and very burdensome both to the writer and to the reader to analyze the course of the Colorado and each of its tributaries to show their relations to the structural features. The subject may be summarized in the single statement that they are entirely independent of the structural features. They run in a majority of cases against the inclinations of the strata and against the topographical slopes. They cut through mountains and plateaus; they enter cliffs, they emerge from them; they enter the lifts of monoclines, they cross faults from the upthrow to the downthrow. They run here obliquely up or down the structural slopes, and there they course along the strike.

There is one and only one way in which we can account for the present positions of these drainage channels. Confining ourselves to the Grand Cañon district (though the same generalization holds good for the entire watershed of the Colorado), we shall find a consistent explanation of the drainage problem by assuming precisely what we have deduced from the discussion of the stratification and displacements; *i. e.*, depressing the whole Grand Cañon platform many thousands of feet and covering it with the Mesozoic and Eocene beds in full volume, reducing at the same time all the faults and flexures until the Carboniferous becomes a smooth platform over the whole district.

To apply this reconstruction to every drainage channel in detail would lead to an interminable discussion of the dryest and most repulsive kind. An example must suffice. Take the Marble Cañon in its relations to the Glen Cañon above it. The Colorado in the Glen Cañon flows through 150 miles of Mesozoic strata, the walls being for the last 50 miles chiefly in the Cretaceous and Jura. At the foot of this chasm the river emerges through a gateway 2,400 deep upon the Marble Cañon (Carboniferous) platform. Just as it approaches the end the Echo Cliff monocline turns up the entire stratigraphic system to the westward, with a displacement, the amount of which is not accurately known, but which exceeds certainly 3,000 feet. The age of this flexure is Tertiary, for it involves the Cretaceous beds and farther north involves the Tertiary. That the river at this point has cut through the entire Mesozoic and Permian, and probably also the Eocene, is self-evident. Imagine now at a given epoch in the early Eocene the river situated only a few hundred feet above sea-level, and all these beds lying beneath its trough. Imagine the monocline smoothed out. This gives us the position of the Marble Cañon platform at the stated epoch; viz, 7,500 to 8,000 feet below sea-level. To maintain the river we must restore that thickness of later strata.

Let us suppose now that these strata thinned rapidly along the course of the Marble Cañon. The supposition speedily raises difficulties. That would imply that the Carboniferous platform had a long upward tilt in that direction at a considerable angle, and that this tilt has since come back to approximate horizontality. Now in truth there is a tilt of this kind, but it amounts to less than one degree, and we may assume that it is congenital so far as the river is concerned. If true it would not materially affect the conclusion. But the arbitrary assumption of a much greater tilt and its subsequent reduction without a trace of evidence is hardly an admissible argument. A still greater difficulty is encountered by applying the test to the Little Colorado, which joins the main river at the foot of the Marble Cañon. This tributary has had the same kind of battles to fight in order to maintain its right of way as the Colorado itself. In no stream could the fact be clearer that it has cut through thousands of feet of strata, and we know pretty nearly how much. It flows northward to its junction

to meet the Colorado flowing south. We must replace beneath it very nearly the same amount of Mesozoic beds as we put beneath the Colorado, otherwise we are left without resource.

Here at the junction the main river turns westward and enters the ascending monocline of the Kaibab. The problem has the same aspect as at the Echo Cliffs, except that the displacements are increased and the consequent amounts of depression required to affect the restoration. The argument also is the same. At the axis of the Kaibab the displacements reach their maximum. West of this axis the depression required for the restoration diminishes as it passes successively each great fault. All along the way we may check the argument from the river by the arguments from the tributaries. The whole forms a system, and in the treatment and conclusions here adopted everything is self-consistent, and no difficulties arise except those which are always inherent in an attempt to bring before the mind a picture of concrete facts whose relations are to be discussed. But if these can be grasped in their entirety the conclusions drawn from them will, I am confident, be deemed unassailable.

I have thus endeavored to group together different categories of facts, in order to bring to the fullest possible tests the inference of the great denudation of the Grand Cañon district. Any deduction if true at all must be true in all its consequences. In the evolution of a region all the great events are intimately associated, and their consequences reach out almost indefinitely. The evolution of the Grand Cañon district involves many complex operations, and the dominant fact is the great erosion of its platform. Every other fact is intimately interwoven with it. In truth it is the major premise of the whole discussion, and we cannot therefore be too careful in scrutinizing the ground upon which it is based. Thus tested, the deduction presents the best possible evidence of verity, which is self-consistency, and coherence with all the facts to which it may be brought into relation. In the course of the argument some data have been anticipated, the evidence of which will appear in subsequent chapters—for example, the Tertiary age of the displacements. This and many other facts will appear in their proper places.

It seems proper here to introduce a general consideration which will

be employed from time to time in the explanation of some notable features of the region.

BASE LEVELS OF EROSION.

In his popular narrative of Explorations of the Colorado River, Powell has employed the above term to give precision to an idea which is of much importance in physical geology. The idea in some form or other has, no doubt, occurred to many geologists, but, so far as known to me, it had not before received such definite treatment nor been so fully and justly emphasized. It may be explained as follows.

Whenever a smooth country lies at an altitude but little above the level of the sea, erosion proceeds at a rate so slow as to be merely nominal. The rivers cannot corrade their channels. Their declivities are very small, the velocities of their waters very feeble, and their transporting power is so much reduced that they can do no more than urge along the detritus brought into their troughs from highlands around their margins. Their transporting power is just equal to the load they have to carry, and there is no surplus energy left to wear away their bottoms. All that erosion can now do is to slowly carry off the soil formed on the slopes of mounds, banks, and hillocks, which faintly diversify the broad surrounding expanse. The erosion is at its base-level or very nearly so. An extreme case is the State of Florida. All regions are tending to base-levels of erosion, and if the time be long enough each region will, in its turn, approach nearer and nearer, and at last sensibly reach it. The approach, however, consists in an infinite series of approximations like the approach of a hyperbola to tangency with its asymptote. Thus far, however, there is the implied assumption that the region undergoes no change of altitude with reference to sea-level; that it is neither elevated nor depressed by subterranean forces. Many regions do remain without such vertical movements through a long succession of geological periods. But the greater portion of the existing land of the globe, so far as is known, has been subject to repeated throes of elevation or depression. Such a change, if of notable amount, at length destroys the pre-existing relation of a region to its base-level of erosion.

If it is depressed it becomes immediately an area of deposition. If it is elevated new energy is imparted to the agents and machinery of erosion. The declivities of the streams are increased, giving an excess of transporting power which sweeps the channels clear of débris; corrasion begins; new topographical features are literally carved out of the land in high relief; long rapid slopes or cliffs are generated and vigorously attacked by the destroying agents; and the degradation of the country proceeds with energy.

It is not necessary that a base-level of erosion should lie at extremely low altitudes. Thus a large interior basin drained by a trunk river, across the lower portions of which a barrier is slowly rising, is a case in point. For a time the river is tasked to cut down its barrier as rapidly as it rises. This occasions slackwater in the courses above the barrier and stops corrasion, producing temporarily a local base-level. Another case is the Great Basin of Nevada. It has no outlet, because its streams sink in the sand or evaporate from salinas. Its valley bottoms are rather below base-level than above it. The general result of causes tending to bring a region to an approximate base-level of erosion is the obliteration of its inequalities.

During the progress of the great denudation of the Grand Cañon district the indications are abundant that its interior spaces have occupied for a time the relation of an approximate base-level of erosion. Throughout almost the entire stretch of Tertiary and Quaternary time the region has been rising, and in the aggregate the elevation has become immense, varying from 11,000 to 18,000 feet in different portions. But it seems that the movement has not been at a uniform rate. It appears to have proceeded through alternations of activity and repose. Whether we can point to more than one period of quiescence may be somewhat doubtful, but we can point decisively to one. It occurred probably in late Miocene or early Pliocene time, and while it prevailed the great Carboniferous platform was denuded of most of its inequalities, and was planed down to a very flat expanse. Since that period the relation has been destroyed by a general upheaval of the entire region several thousands of feet. The indications of this will appear when we come to the study of the interior spaces of the Grand Cañon district and of the Grand Cañon itself. To this study we now proceed.

CHAPTER V.

THE TOROWEAP AND THE GRAND CAÑON.

From Kanab to Pipe Spring—Crossing the desert—The Permian Cliffs—Desert vegetation—The Wild Band water-pockets—Scenery upon the desert platform—Distant views of the terrace cliffs and the volcanoes of the Uinkaret—The Wonsits Valley—Basaltic lavas and cinder cones of the Uinkaret—The head of the Toroweap Valley—Descent of the valley—Distant view of the cañon wall—The Witches' water-pocket.—The walls of the Toroweap, with their pinnacles, amphitheaters, and alcoves—The Toroweap fault—Lava cascades descending from the Uinkaret—Gigantic architecture—The opening of the valley into the main chasm—The great esplanade—The inner gorge—Divisions of the Carboniferous system exposed in the chasm—Grandeur of the scenery and systematic character of the profiles—Vulcan's Throne—Views up and down the main chasm—The view up the Toroweap—The fault and its visible details—Age of the dislocation—View of the basaltic cones of the Uinkaret and of the lava cascades—View across the gorge—Ruined crater on the brink—Dykes in the cañon wall—Recency of the excavation of the inner gorge and the rapidity of its excavation—Descent of the inner chasm wall to the river—View of the cañon below—Great corrasive power of the river—Significance of the Toroweap Valley—It is the vestige of ancient drainage—The excavation of the chasm is the work performed under an arid climate—The age of the entire chasm is comparatively recent with a probable beginning near the close of the Miocene.

The present chapter will contain an account of a journey from the village Kanab to the Toroweap Valley, and a description of the middle portion of the Grand Cañon. Kanab is the usual rallying place and base of operations of the survey in these parts, being located on the only living stream between the Virgen and the Paria.

The first stage of the journey from Kanab to Pipe Spring is an easy one. It leads southwestward to a gap cut through the low Permian terrace and out into the open desert beyond. The road, well traveled and easy, then turns westward and at length reaches the spring twenty miles from Kanab Pipe Spring is situated at the foot of the southernmost promontory of the Vermilion Cliffs, and is famous throughout southern Utah as a watering place. Its flow is copious and its water is the purest and best throughout that desolate region. Ten years ago the desert spaces outspreading to the southward were covered with abundant grasses, affording

rich pasturage to horses and cattle. To-day hardly a blade of grass is to be found within ten miles of the spring, unless upon the crags and mesas of the Vermilion Cliffs behind it. The horses and cattle have disappeared, and the bones of many of the latter are bleached upon the plains in front of it. The cause of the failure of pasturage is twofold. There is little doubt that during the last ten or twelve years the climate of the surrounding country has grown more arid. The occasional summer showers which kept the grasses alive seldom come now, and through the long summer and autumn droughts the grasses perished even to their roots before they had time to seed. All of them belong to varieties which reproduce from seed, and whose roots live but three or four years. Even if there had been no drought the feeding of cattle would have impoverished and perhaps wholly destroyed the grass by cropping it clean before the seeds were mature, as has been the case very generally throughout Utah and Nevada.

Northeastward the Vermilion Cliffs extend in endless perspective towards Kanab, and beyond to the Paria. Northwestward, with growing magnitude, they extend towards the Virgen, ever forming a mighty background to the picture. To the southward stretches the desert, blank, lifeless, and as expressionless as the sea. For five or six miles south of the Pipe Spring promontory there is a gentle descending slope, and thence onward the surface feebly ascends through a distance of thirty miles to the brink of the Grand Cañon. Thus the range of vision is wide, for we overlook a gentle depression of great extent. Though the general impression conveyed is that of a smooth or slightly modulated country, yet we command a far greater expanse than would be possible among the prairies. To the southeastward the Kaibab looms up, seemingly at no great distance, and to the southwestward the flat roof of Mount Trumbull is more than a blue cloud in the horizon. Towards this latter mountain we take a straight course. The first few miles lie across drifting sands bare of all vegetation. The air is like a furnace, but so long as the water holds out the heat is not enervating and brings no lassitude. Everything is calm and still, except here and there a hot whirling blast, which sends up a tall, slender column of dust, diffusing itself in the air. At a slow pace, the sand-hills at length are passed and we enter upon a hard, firm soil, over which we move more

rapidly. Just here, and for three or four miles in either direction, the Permian terrace has been obliterated. It has been beveled off by erosion and buried beneath the wash brought down from the foot of the Vermilion Cliffs to the northward. But seven miles from Pipe Spring, the Permian terrace springs up out of the earth, scarped by its characteristic cliff. Stretching northwestward it increases in altitude, becoming at last 800 to 1,000 feet high. At its summit is seen the Shinarump conglomerate, of a pale brown color, and beneath are the gorgeous hues of the shales. Nothing can surpass the dense, rich, and almost cloying splendor of the red-brown seen in these shales. They suggest the color of old mahogany, but are much more luminous and quite uniform. Under them are belts of chocolate, slate, lavender, pale Indian red, and white. Very wonderful, too, is the evenness of the bedding, which is brought out in great clearness and sharpness by the etching of minute layers of clays holding selenite. Between the shales and overlying conglomerate careful scrutiny enables us to detect an unconformity by erosion without any unconformity of dip. As stated in a preceding chapter, Mr. Walcott fixed provisionally the separating horizon between the Permian and Trias at this unconformable contact.

Along the route the vegetation is scanty indeed. Several forms of cactus are seen looking very diseased and mangy, and remnants of low desert shrubs browsed to death by cattle. Yet, strangely enough, there is one plant and one alone that seems to flourish. It is the common sunflower, found anywhere from Maine to Arizona, and seeming indifferent to the vicissitudes of climate.

About 18 miles from Pipe Spring the trail leads gently down into a broad shallow valley known as the Wild Band pockets. The drainage from the fronts of the Permian Cliffs, now far to the northward, here collects into a gulch, which gradually deepens and becomes a tributary of Kanab Cañon. In every stream-bed may be found many depressions which would hold water even though the sources of supply were cut off. This is as true of wet-weather channels as of perennial streams. After the infrequent showers, and after the surface waters have ceased to run, the bed of the stream will still retain pools of water, provided the bottom of it is of a consistency which will prevent it from filtering away. To these pools the people of the

west have given the name of "water-pockets." They are very common in the stream-beds which bear away the wash from the Permian and lower Triassic shales. These shales yield a very fine impervious clay, which forms an excellent "puddling" for water holes and basins. The Wild Band pockets have received their name from the fact that they are the resort of bands of wild horses that roam over these deserts, far from human haunts, ranging from spring to spring, which they visit by stealth only at night, and never so long as they can find chance water in these and other pockets. Beyond the Wild Band Valley there is a slight ascent to a rocky platform, consisting of the summit beds of the Carboniferous. In the course of 20 miles we have crossed the entire Permian series, which now lies to the north of us. A few stunted cedars, most of which are dead or dying of drought, are scattered over this platform and give us until nightfall some slight shelter from the sun. It is as good a camping place as we are likely to find, and if we are fortunate enough to reach it after a copious shower, the hollows and basins in the flat rocks may contain a scanty supply of clear rain-water. It is a good locality, also, from which we may overlook the outspreading desert, which is not without charms, however repulsive in most respects.

To the northward rises the low escarpment of the Permian, forming a color picture which is somewhat indistinct through distance, but weird because of its strange colors and still stranger forms. Beyond and in the far distance rise the towering fronts of the Vermilion Cliffs, ablaze with red light from the sinking sun. To the eastward they stretch into illimitable distance, growing paler but more refined in color until the last visible promontory seems to merge its purple into the azure of the evening sky. Across the whole eastern quarter of the horizon stretches the long level summit of the Kaibab as straight and unbroken as the rim of the ocean. To the southwestward rises the basaltic plateau of Mount Trumbull, now presenting itself with somewhat imposing proportions. Around it a great multitude of basaltic cinder cones toss up their ominous black waves almost as high as Trumbull itself. Their tumultuous profiles and gloomy shades form a sharp contrast with the rectilinear outlines and vivid colors of the region roundabout.

At dawn we moved onward, reaching soon the summit of a hill which descends two or three hundred feet to a broad flat depression called the Wonsits Plain. It is a very barren and smooth expanse, dotted with a few moldering buttes of Upper Carboniferous rocks, now wasted to their foundations. The plain is about seven miles in width, and on the further side rises a low mesa of great extent capped with basalt. It is the Uinkaret. Beyond the nearer throng of basaltic cones Mount Trumbull rises with a striking aspect dominating strongly the entire western landscape. The smaller cones are now seen to be very numerous, and all of them are apparently perfect in form, as if time had wrought no great ravage among them. The *lapilli* and *peperino*, with which they are covered, have become dull red by the oxidation of the iron, and this peculiar color is easily recognized though the cones are still far away. Just before reaching the basaltic mesa we must make our choice between two routes to the Toroweap, one direct, the other very circuitous. No spring is to be found until we reach the further side of Mount Trumbull, but we know of a large water-pocket on this side, which has never been known to dry up. The spring water is sure to be good, but the water in the pocket will depend for its quality upon the length of time which has passed since the last heavy rain. Let us here choose the shorter one, and go to the water-pocket.

Ascending the mesa, which rises abruptly about 200 feet above the Wonsits Plain, we find ourselves at once upon the basalt. The ground is paved with cinders and fragments half buried in soil, the débris of decaying lava sheets. These sheets are rarely of any great thickness, seldom exceeding 30 or 40 feet, and often much less, and none of the individual eruptions of lava seem to have covered any very great expanse. Probably the area covered by the largest would be less than a square mile. They show no perceptible differences in composition or texture, and all are basalts of the most typical variety—very black and ferruginous in the unweathered specimens and speckled with abundant olivine. At the time of eruption they appear to have been in a state of perfect liquidity, spreading out very thin and flowing rapidly and with ease. In none of them has erosion wrought much havoc, though here and there some local destruction has been effected, most conspicuously upon the edges of the principal mesa

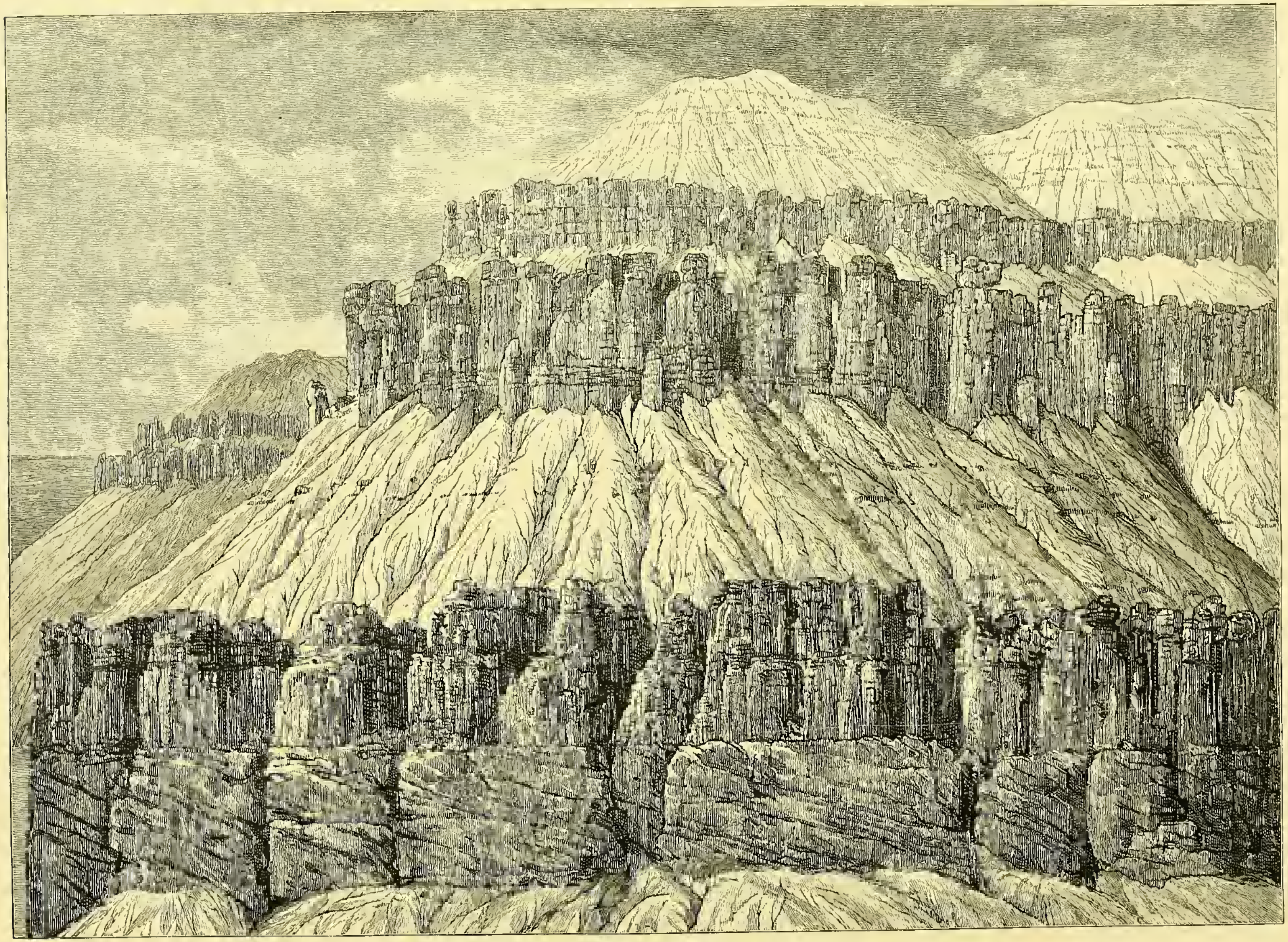
where the sheets have been undermined and their fragments scattered upon the plain below. The cones, which stand thick around us, are still in good preservation. They are of ordinary composition—mere piles of cinders thrown out of central vents and dropping around it. The fume and froth of the lava surfaces, the spongy inflated blocks, the lapilli and peperino, are not greatly changed, though all of them here show the oxidation of the iron. We wonder what their age may be; what time has elapsed since they vomited fire and steam. But there is no clew—no natural record by which such events can be calendared. Historically, they have doubtless stood in perfect repose for very many centuries. Not a trace of activity of any kind is visible, and they are as perfectly quiescent as the dead volcanoes of the Auvergne or of Scotland. Geologically, they are extremely recent; yet even here where historic antiquity merges into geologic recency the one gives us no measure of the other.

Following a course which winds among the silent cones and over rough, flat surfaces of lava beds half buried in drifting sands, we at length reach the border of a slight depression, into which we descend. It is hardly noteworthy as a valley just here, and might be confounded with any one of the innumerable shallow water courses which occur round about; only when we look beyond we see it growing broader and much deeper. It is the head of the Toroweap. Upon its smooth bottom is a soft clayey soil, in which desert shrubs and stunted sage-brush grow in some abundance. Here and there a cedar, dwarfed indeed, but yet alive, displays a welcome green, and upon the valley slopes are a few sprays of grass. The valley bottom descends at a noticeable rate to the southward, and as we put the miles behind us we find the banks on either side rising in height, becoming steeper, and at last displaying rocky ledges. In the course of six or seven miles the left side has become a wall 700 feet high, while the other side, somewhat lower, is much broken and craggy. Huge piles of basalt lie upon the mesa beyond, sheet upon sheet, culminating in a cluster of large cones. At length the course of the valley slightly deflects to the left, and as we clear a shoulder of the eastern wall, which has hitherto masked its continuation, a grand vista breaks upon the sight. The valley stretches away to the southward, ever expanding in width; the

walls on either side increase in altitude, and asume profiles of wonderful grace and nobility. Far in the distance they betoken a majesty and grandeur quite unlike anything hitherto seen. With vast proportions are combined simplicity, symmetry, and grace, and an architectural effect as precise and definite as any to be found in the terraces. And yet these walls differ in style from the Trias and Jura as much as the Trias and Jura differ from each other. In the background the vista terminates at a mighty palisade, stretching directly across the axis of vision. Though more than 20 miles distant it reveals to us suggestions of grandeur which awaken feelings of awe. We know instinctively that it is a portion of the wall of the Grand Cañon.

The western side of the valley is here broken down into a long slope descending from the cones clustered around the base of Mount Trumbull, and is covered with broad flows of basalt. Turning out of the valley we ascend the lava bed, which has a very moderate slope, and about a mile from the valley we find the Witches' Water Pocket. In every desert the watering places are memorable, and this one is no exception. It is a weird spot. Around it are the desolate Phlegræan fields, where jagged masses of black lava still protrude through rusty, decaying cinders. Patches of soil, thin and coarse, sustain groves of cedar and piñon. Beyond and above are groups of cones, looking as if they might at any day break forth in renewed eruption, and over all rises the tabular mass of Mount Trumbull. Upon its summit are seen the yellow pines (*P. ponderosa*), betokening a cooler and a moister clime. The pool itself might well be deemed the abode of witches. A channel half-a-dozen yards deep and twice as wide, has been scoured in the basalt by spasmodic streams, which run during the vernal rains. Such a stream cascading into it has worn out of the solid lava a pool twenty feet long, nearly as wide, and five or six feet deep. Every flood fills it with water, which is good enough when recent, but horrible when old. Here, then, we camp for the night.

Filling the kegs at daylight, we descend again into the Toroweap and move southward. Our attention is strongly attracted by the wall upon the eastern side. Steadily it increases its mass and proportions. Soon it becomes evident that its profile is remarkably constant. We did not notice



A GABLE WITH PINNACLES.—THE TOROWEAP

this at first, for we saw in the upper valley only the summit of the palisade; but as the valley cuts deeper in the earth the plan and system begin to unfold. At the summit is a vertical ledge, next beneath a long Mansard slope, then a broad plinth, and last, and greater than all, a long, sweeping curve, gradually descending to the plain below. Just opposite to us the pediments seem half buried, or rather half risen out of the valley alluvium. But beyond they rise higher and higher until in the far distance the profile is complete. In this escarpment are excavated alcoves with openings a mile wide. As soon as we reach the first one, new features appear. The upper ledge suddenly breaks out into a wealth of pinnacles and statues standing in thick ranks. They must be from 100 to 250 feet high, but now the height of the wall is more than a thousand feet, and they do not seem colossal. Indeed, they look like a mere band of intricate fretwork—a line of balustrade on the summit of a noble façade. Between the alcoves the projecting pediments present gable-ends towards the valley-plain. Yet whithersoever the curtain wall extends the same profile greets the eyes. The architect has adhered to his design as consistently and persistently as the builders of the Thebaid or of the Acropolis. As we pass alcove after alcove, and pediment after pediment, they grow loftier, wider, and deeper, and the decoration becomes more ornate. At length we pass one which is vast indeed. It is recessed back from the main front three-fourths of a mile, and shows three sides of an oblong room with walls 1,800 feet in height. The fourth side is obliterated and the space opens into the broad valley. Wonderfully rich and profuse are the pinnacles and statues along the upper friezes. The fancy is kindled as the eye wanders through the inclosure.

We look across the valley, which is here three miles in width, and behold the other wall, which presents an aspect wholly different, but quite as interesting. The western wall of the Toroweap is here lower than the eastern, but still is more than a thousand feet high. The geologist soon surmises that along the valley bottom runs a fault which drops the country on the west several hundred feet, and the conjecture soon becomes certainty. Above and beyond the western escarpment is the platform of the Uinkaret Plateau. Upon its summit is a throng of large basaltic cones in perfect preservation. Streams of lava larger than any hitherto seen have poured

from their vents, flooding many a square mile of mesa land, and in the wide alcoves they have reached the brink of the wall and cascaded over it. Still pouring down the long taluses they have reached the valley bottom below and spread out in wide fields, disappearing underneath the clayey alluvium, which has buried much of their lower portions. The appearance of these old lava cascades, a mile or more wide, a thousand feet high, and black as Erebus, is striking in the extreme. There are five of these basaltic cataracts, each consisting of many individual *coulées*. Between them the bold pediments of brightly-colored Carboniferous strata jut out into the valley.

At length we approach the lower end of the Toroweap. The scenery here becomes colossal. Its magnitude is by no means its most impressive feature, but precision of the forms. The dominant idea ever before the mind is the architecture displayed in the profiles. It is hard to realize that this is the work of the blind forces of nature. We feel like mere insects crawling along the street of a city flanked with immense temples, or as Lemuel Gulliver might have felt in revisiting the capital of Brobdingnag, and finding it deserted. At the foot of the valley the western wall is nearly 1,500 feet high, the eastern about 2,000, and the interval separating them is about three miles. Suddenly they turn at right angles to right and left, and become the upper wall of the Grand Cañon of the Colorado. The Toroweap now opens into the main passageway of the great chasm. The view, however, is much obstructed. At the foot of the eastern gable is a medley of rocky ledges of red sandstone, while around the base of the western gable are large masses of basalt reaching more than half-way across the valley. In front rises a crater, which is about 600 feet high, seemingly a mere knoll in the midst of this colossal scenery. Beyond it, and five miles distant, rises the palisade which forms the southern upper wall of the chasm, stretching athwart the line of vision interminably in either direction. Its altitude is apparently the same as that of the palisade above us, and its profile is also identical. Climbing among the rocky ledges which lie at the base of the escarpment, we at length obtain a stand-point which enables us to gain a preliminary view of the mighty avenue. To the eastward it stretches in vanishing perspective forty miles or more. Between symmetric

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INNER GORGE AT TOROWEAP—LOOKING EAST.

walls 2,000 feet high and 5 miles apart is a plain, which in comparison with its limiting cliffs might be regarded as smooth, but which in reality is diversified by rocky hummocks and basins, and hillocks where patches of soil give life to scattered cedars and piñons. Of the inner chasm nothing as yet is to be seen. Moving outward into this platform we find its surface to be mostly bare rock, with broad shallow basins etched in them, which hold water after the showers. There are thousands of these pools, and when the showers have passed they gleam and glitter in the sun like innumerable mirrors. As we move outward towards the center of the grand avenue the immensity and beautiful proportions of the walls develop. The vista towards the east lengthens out and vanishes against the blue ramp of the Kaibab, which lies as a cloud upon the horizon. To the west the view is less symmetric and regular, and the eye wanders vaguely among cliffs and buttes of stupendous magnitude, displaying everywhere the profile with which we have become of late familiar. Much of the distance towards the west is obstructed by the crater, but the portions in view bewilder us by the great number of objects presented, and oppress us by their magnitudes. At a distance of about two miles from the base of the northern wall we come suddenly upon the inner chasm. We are not conscious of its proximity until we are within a few yards of it. In less than a minute after we have recognized the crest of the farther wall of this abyss we crane over its terrible brink and gaze upon the water of the river full 3,000 feet below.

The scene before us is a type of the Grand Cañon throughout those portions which extend through the Kanab, Uinkaret, and Sheavwits Plateaus. The plan and section here presented are quite simple. They consist of a broad upper chasm from five to six miles in width with walls varying in altitude but little from 2,000 feet. Between these escarpments is a rocky plain, rough indeed, but in the overpowering presence of such walls seeming relatively smooth and uniform In this floor is cut the inner chasm 3,000 feet deep and from 3,500 to 4,000 feet wide from crest to crest. The true profiles will be best understood by consulting the diagram (Fig. 1), which is drawn to scale. The strata in which the chasm is excavated are all of Carboniferous age excepting three or four hundred feet at the bottom of the gorge. The strata beneath the Carboniferous are at present believed to be

lower Silurian, and their contact with the Carboniferous is unconformable, both by dip and by erosion. In the upper part of the palisades which form the wall of the upper chasm we find at the summit two series of limestones. The upper contains an abundance of siliceous matter, one portion of which is intimately disseminated through the mass while another portion is aggregated into myriads of cherty nodules varying from two to ten inches in diameter. The lower one is a purer limestone with few nodules. The cherty members form a nearly vertical band at the summit of the wall; the purer members form a Mansard slope beneath, covered with talus. The total thickness of the limestones is about 700 to 750 feet. Beneath them come sandstones a little more than 250 feet thick, which form everywhere a vertical plinth or frieze. They are very adamantine in texture, and one of the members, about 180 feet thick, is in every exposure seen to be uniformly cross-bedded. Under the cross-bedded sandstone is a mass of thinly bedded and almost shaly sandstones, having an aggregate thickness very closely approximating to 1,000 feet. They are of an intensely brilliant red color, but are, in greatest part, covered with a heavy talus of imperishable cherty nodules, fragments of the cross-bedded sandstones, and spalls of limestone shot down from above. The color of these is pale gray, with occasionally a yellowish or creamy tinge. The brilliant red sandstones form the long curved slope which descends from the plinth of cross-bedded sandstone to the plain below.

The walls of the inner gorge have at the summit about 325 feet of hard sandstone of a brown-red color. Beneath the sandstone are about 1,800 feet of impure limestone in layers of the most massive description Very

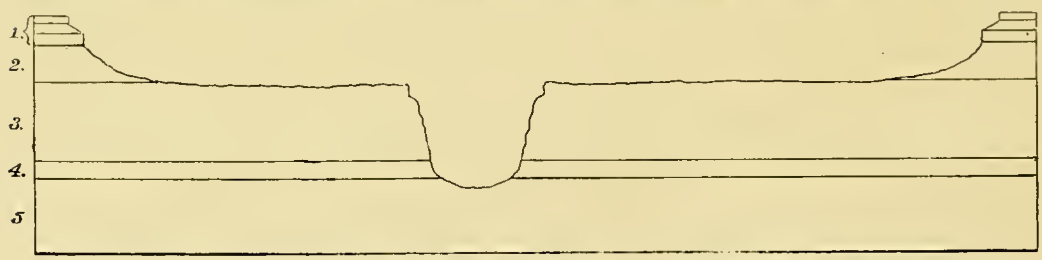


FIG. 1.—Section of the Grand Cañon at the foot of the Toroweap Valley. 1. Upper Aubrey; 2. Lower Aubrey; 3. Red Wall; 4. Base of the Carboniferous; 5. Lower Silurian and Archæan unconformable. Scale one mile to the inch.

few such ponderous beds of limestone are found in any part of the world. The color is deep red with a purplish tone, but the brilliancy of the color-

ing is notably weakened by weathering. Still lower are red-brown sandstones again, having a dark and strong shade and lying in very massive beds. The strata forming the walls of the outer chasm from the summit to the plain below are designated the Aubrey group, and this is again subdivided at the base of the cross-bedded plinth into upper and lower Aubrey groups. The two subdivisions are believed to be the equivalents, in age, of the coal measures of Pennsylvania and England. The strata disclosed in the inner gorge correspond in age to the lower Carboniferous of those countries, and are here termed the Red Wall group. Some uncertainty exists regarding the beds which lie at the base of the conformable series deep down in the chasm, but they are regarded at present as being just what they seem and just what they would naturally be inferred to be—a part of the Carboniferous system. Of the strata at the bottom of the cañon, we shall have more to say hereafter. They are regarded at present as being of lower Silurian or Primordial age.

The observer who, unfamiliar with plateau scenery, stands for the first time upon the brink of the inner gorge, is almost sure to view his surroundings with commingled feelings of disappointment and perplexity. The fame of the chasm of the Colorado is great; but so indefinite and meager have been the descriptions of it that the imagination is left to its own devices in framing a mental conception of it And such subjective pictures are of course wide of the truth. When he first visits it the preconceived notion is at once dissipated and the mind is slow to receive a new one. The creations of his own fancy no doubt are clothed with a vague grandeur and beauty, but not with the grandeur and beauty of Nature. When the reality is before him the impression bears some analogy to that produced upon the visitor who for the first time enters St. Peter's Church at Rome. He expected to be profoundly awe-struck by the unexampled dimensions, and to feel exalted by the beauty of its proportions and decoration. He forgets that the human mind itself is of small capacity and receives its impressions slowly, by labored processes of comparison. So, too, at the brink of the chasm, there comes at first a feeling of disappointment; it does not seem so grand as we expected. At length we strive to make comparisons. The river is clearly defined below, but it looks about large enough to turn a village

grist-mill; yet we know it is a stream three or four hundred feet wide. Its surface looks as motionless as a lake seen from a distant mountain-top. We know it is a rushing torrent. The ear is strained to hear the roar of its waters and catches it faintly at intervals as the eddying breezes waft it upwards; but the sound seems exhausted by the distance. We perceive dimly a mottling of light and shadow upon the surface of the stream, and the flecks move with a barely perceptible cloud-like motion. They are the fields of white foam lashed up at the foot of some cataract and sailing swiftly onward.

Perhaps the first notion of the reality is gained when we look across the abyss to the opposite crest-line. It seems as if a strong, nervous arm could hurl a stone against the opposing wall-face; but in a moment we catch sight of vegetation growing upon the very brink. There are trees in scattered groves which we might at first have mistaken for sage or desert furze. Here at length we have a stadium or standard of comparison which serves for the mind much the same purpose as a man standing at the base of one of the sequoias of the Mariposa grove. And now the real magnitudes begin to unfold themselves, and as the attention is held firmly the mind grows restive under the increasing burden. Every time the eye ranges up or down its face it seems more distant and more vast. At length we recoil, overburdered with the perceptions already attained and yet half vexed at the inadequacy of our faculties to comprehend more.

The magnitude of the chasm, however, is by no means the most impressive element of its character; nor is the inner gorge the most impressive of its constituent parts. The thoughtful mind is far more deeply moved by the splendor and grace of Nature's architecture. Forms so new to the culture of civilized races and so strongly contrasted with those which have been the ideals of thirty generations of white men cannot indeed be appreciated after the study of a single hour or day. The first conception of them may not be a pleasing one. They may seem merely abnormal, curious, and even grotesque. But he who fancies that Nature has exhausted her wealth of beauty in other lands strangely underestimates her versatility and power. In this far-off desert are forms which surprise us by their unaccustomed character. We find at first no place for them in the range of our

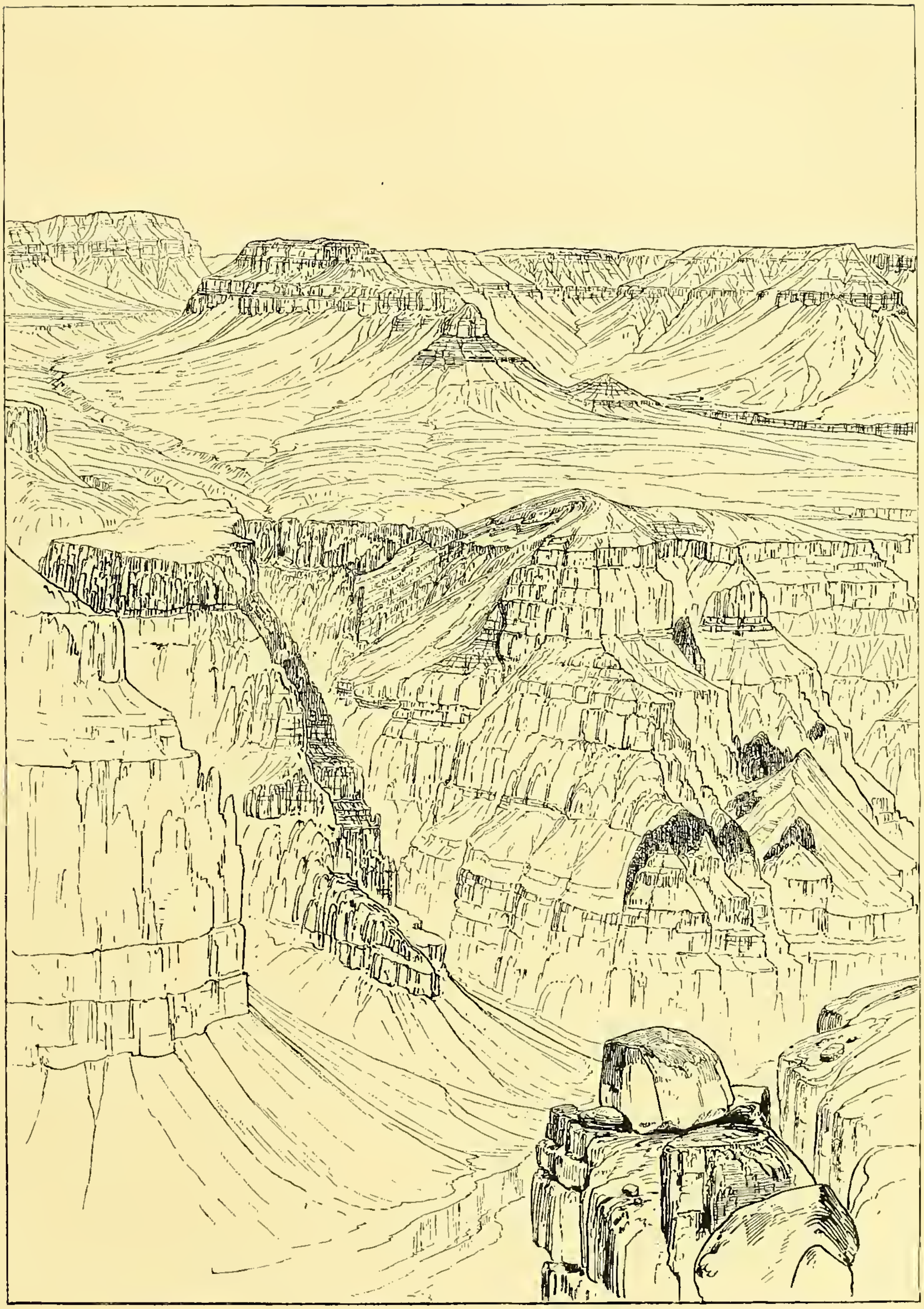
conventional notions. But as they become familiar we find them appealing to the æsthetic sense as powerfully as any scenery that ever invited the pencil of Claude or of Turner.

The inner gorge, as we sit upon its brink, is indeed a mighty spectacle; but as we withdraw a little it fades out of view, and, strangely enough, the sublimity of the scene is not very greatly impaired. It is, after all, a mere detail, and the outer chasm is the all-engrossing feature. On either side its palisades stretch away to the horizon. Their fronts wander in and out, here throwing out a gable, there receding into a chamber, or gaping widely to admit the entrance of a lateral chasm. The profile is ever the same. It has nothing in common with the formless, chaotic crags, which are only big and rough, but is definite, graceful, architectural, and systematic. The width of the space inclosed between the upper walls is one of the most essential elements of the grandeur.. It varies from five to six miles. If it were narrower the effect would be impaired; nor could it be much wider without diluting and weakening the general effect. This proportion seems quite just. It is a common notion that the distinctive and overruling feature of the great chasm is its narrowness relatively to its depth. No greater mistake could be made. Our highest conceptions of grandeur are most fully realized when we can see the greatest mass. We must have amplitude in all of the three dimensions, length, breadth, and depth, and that spectacle is in point of magnitude the grandest which has the three dimensions so proportioned and combined as to make the most of them. Another common and mistaken idea is that the chasm is pervaded by a deep, solemn gloom. The truth is almost the reverse. In the depths of the inner gorge there is a suggestion of gloom, but even in the narrower portions there is seldom less than sixty degrees of sky from crest to crest, and a hundred and sixty along the track of the river. In the outer chasm the scene is unusually bright. The upper half of the palisades has a pale, ashy, or pearl-gray color, which is very lustrous, and this sometimes gives place to a creamy or Naples yellow tint in the frieze of cross-bedded sandstone. The lower Aubrey sandstones are bright-red, but they are in great part masked by the talus shot down from the pale-gray limestones above, and peep out in lustrous spots where the curtain of the talus is drawn aside.

There is nothing gloomy about such colors. Under a burning sun that is rarely clouded they have a brilliancy seldom seen in any rocks, and only surpassed by the sugary whiteness of the Jurassic sandstone or the brilliant red of the Vermilion Cliffs.

Directly in the southward prolongation of the axis of the Toroweap Valley there stands a basaltic cinder cone immediately upon the brink of the inner gorge. Its altitude above the surrounding plain is 580 feet. The summit is readily gained, and it is an admirable stand-point from which the entire panorama may be viewed. We named it Vulcan's Throne. To the eastward about forty miles of the main chasm are well in view. The altitude of the cone, though small in comparison with surrounding objects, is sufficient to bring into view about eight miles of the opening of the inner gorge, while in the foreground its depths are seen. To the westward the scenery is much more broken and diversified. The chasm is seen through the entire stretch in the Uinkaret Plateau and reaching a few miles into the Sheavwits. But about twenty miles westward it makes a southward turn and disappears. From the north the Toroweap Valley descends from near Mount Trumbull. It is cut down only to the base of the Upper Cañon Wall and opens into the main chasm on the level of the plain above the inner gorge. There is reason to believe that at some prior epoch it was cut a few hundred feet deeper than its present floor, and was subsequently built up by many floods of basalt coming from the cones on the Uinkaret and by considerable quantities of alluvium washed from its cliffs and overlooking mesas. On the south side of the Grand Cañon is a valley quite the counterpart of the Toroweap. It enters the main chasm directly opposite to the Toroweap, so that the two form the arms of a transept, the main chasm being regarded as the nave. Vulcan's Throne is situated almost exactly at the intersection of the axes of nave and transept.

It would be difficult to find anywhere else in the world a spot yielding so much subject-matter for the contemplation of the geologist; certainly there is none situated in the midst of such dramatic and inspiring surroundings. The chasm itself, with its marvelous story of erosion, and the two lateral valleys adding their quotas of information are grand subjects indeed; but other themes are disclosed which are scarcely less surprising and sug-



DIKES IN THE CAÑON WALL.

gestive. The cone stands immediately upon the line of a large fault; and never was a fault and its consequences more clearly displayed. The Toroweap fault is one of six which at wide intervals traverse the Grand Cañon district from north to south with a rude approximation to parallelism. It is the smallest of the six. Twenty miles north of the chasm no trace of it is visible. Its beginning there is small, but as it approaches the chasm it increases in the amount of displacement; and at the crossing of the river the shear or "throw" is between 600 and 700 feet. In the wall-face of the inner gorge it is disclosed as clearly as a draughtsman could delineate it on paper. The masses of horizontal limestones and sandstones, displaying their fretted edges and lines of bedding, advance from the eastward in the face of the wall until they reach the vertical fault plane. Then they "break joints" and drop at once six or seven hundred feet, and continue westward as before, but at a lower level. The whole topography goes with it. Looking beyond to the upper wall of the outer chasm the "jog" where the break occurs is plainly seen. The whole platform of the country is dropped to the westward. The plain between the upper palisades or esplanade, as it will be hereafter termed, descends by a single step from east to west across the fault by an amount equal to the displacement, and the inner gorge and the whole chasm are correspondingly reduced in depth.

Excepting the dislocation itself, the faulting does not appear to have been accompanied by any injury to the strata. Not a trace of shattering, crumbling, or mashing of the beds is discernible. All looks as clean and sharp as if it had been cut with a thin saw and the smooth faces pressed neatly together. But the only attainable view of it is from the distance of a mile; yet miles here are less than furlongs in other countries, and all details as well as broader features are upon the Brobdingnagian scale. What a nearer view might disclose is of course impossible to conjecture. The plane of the fault is about vertical, though there seems to be a slight inclination to the east, which may be apparent only and a result of perspective.

After a careful study of the surroundings of the fault, it becomes apparent that it is of recent occurrence in comparison with other events which have been in progress here. The tenor of all evidence bearing upon the

subject goes to show that these faults were not suddenly produced by violent convulsions, but gradually developed through long stretches of time, and inch by inch or foot by foot. The Toroweap fault gives no evidence of being exceptional in this respect. Its recency is disclosed by many facts. It is seen that the amount of erosion in the face of the transverse "cliff of displacement" produced by the faulting is very small. This cliff has not receded from the fault plane to any considerable extent; yet the giant palisades which wall the outer chasm have receded from the median line of the cañon more than two miles since the corrasion of the river laid bare the edges of their strata. It seems very plain that the outer chasm had been formed and attained very nearly its present condition before the fault started. But there is still more conclusive evidence of recency. At the foot of the southern palisade and at the jaws of the lateral valley are several basaltic craters. They look like mere bee-hives under the eaves of such an escarpment, though in truth they are four or five hundred feet high. From their vents streams of basalt are seen flowing down in the lateral valley across the fault plane, and clear to the brink of the inner abyss. The fault shears the lava floods as neatly as it does the Red Wall limestone. Many other facts might be cited to the same purport, but this one is so conclusive that nothing further is necessary. We shall find similar evidences of recency when we come to the study of the great Hurricane fault.

Another subject which will awaken the enthusiasm of the geologist who visits this unique spot is the volcanic phenomena. Turning to the northwestward he beholds the heights of the Uinkaret. Upon its broad expanse stand many basaltic craters in perfect preservation. We know of about a hundred and fifty distinct cones in this plateau, included in the space which lies between the Grand Cañon and a limit forty miles north of it. But it is in the vicinity of the chasm that they cluster most thickly together and present the largest proportions. This part of the Uinkaret is thickly covered with basalt, above which rises the tumultuous throng of craters. Very many wide and deep floods of basalt have poured over the edge of the plateau into the lower Toroweap Valley and upon the great esplanade of the cañon, 1,500 to 1,800 feet below, and, spreading out into

wide fields, have reached the brink of the inner gorge. Pouring over its brink, the fiery cascades have shot down into the abyss and pursued their way many miles along the bed of the river. At one epoch they had built up the bed of the Colorado about 400 feet, but the river has scoured out its channel again and swept them all away, regaining its old level, and is now cutting the sandstones below. The spectacle of the lava floods descending from the Uinkaret, as seen from Vulcan's Throne, is most imposing. It tells the story so plainly that a child could read and understand it. Compared with many classic volcanic regions the volcanism of the Uinkaret is a small affair. But in those classic regions the mind does not come into direct contact with the enormity of the facts by a single glance of the eye. But here, if kind Asmodeus were to lift the basaltic roof of the plateau, we should see no more than we do now. The boldness of the picture is much increased by the pediments of Carboniferous strata projecting from the body of the plateau, showing the brilliant colors of the strata and their sharply defined architecture, with the dark masses of basalt wrapping around them. Hard by, and almost within hail, is a superb gable projecting between two broad floods of lava, and so beautifully proportioned and richly colored that we cannot help wishing to transport it by magic to some more habitable region.

Turning now to the southward and looking across the inner gorge to its opposing wall, a strange spectacle of havoc and wreck is presented to our view. A lateral gorge or amphitheater is excavated in the chasm wall, very nearly as deep as the main abyss. Here the action of volcanic forces is displayed in a manner which is quite unique. At the summit of the wall of the inner gorge, just at the angle where it swings backward into the amphitheater, a ruined basaltic crater stands upon the very brink. Indeed its lower portions on two sides are undermined by the falling of the wall, and the anatomy of the cone is laid open to view. And not only that, but the very dike through which the lava came up is disclosed to a depth of half a mile. There are also other dikes which show their edges in the wall of the amphitheater in transverse vertical section, and which outcrop in the main wall of the gorge (Fig. 2). The strike of these dikes is parallel to the river. One of them protrudes from the sloping front of the wall

about 1,600 feet below the summit; another protrudes about 1,200 feet below, and still another about 600 below the crest. A fourth dike apparently leads directly to the vent of the cone and no doubt constituted the pipe of the volcano. Now a brief scrutiny shows very conclusively that these dikes were made when the lateral gorge and main chasm had much less depth than that which they have now attained. It is manifestly impossible that a dike of basalt could rise hundreds or even two thousand feet

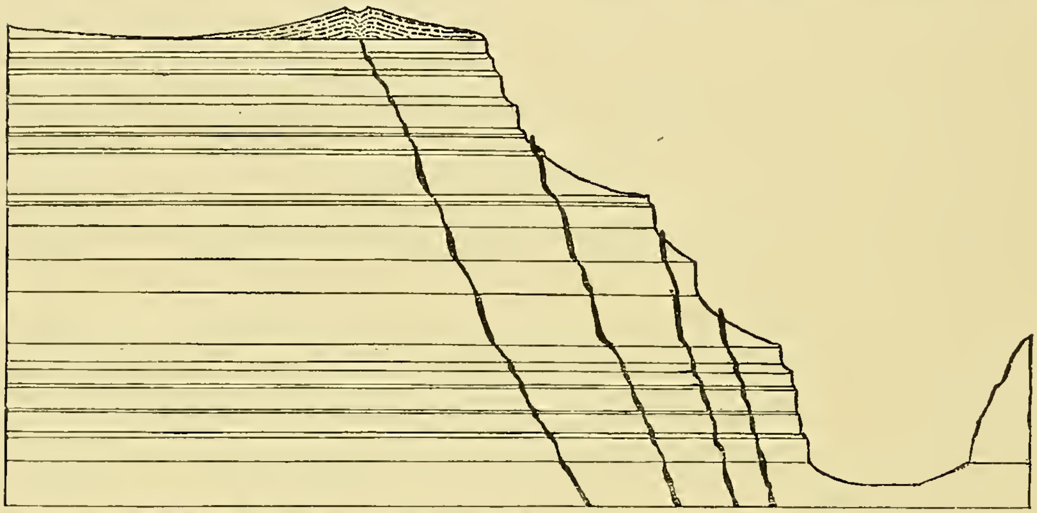


FIG. 2.—Dikes in the wall of the inner gorge of the cañon, as shown in transverse vertical sections in the wall of a lateral amphitheater. Toroweap.

through solid limestone, with one edge of it protruding laterally out of the face of a scarp wall. And if the chasm had approximately its present depth the lava would surely have burst from the face of the wall at or near the bottom. In no way does it seem possible to account for them in their present positions and relations except by assuming that the depth and width of the gorge was then but a small fraction of the present dimensions. We know that basalts play curious pranks sometimes, but they always keep within the limits of possibilities. On the other hand, the chasm must have had some notable depth, for in a few places are seen remnants of tufa beds descending from the cone over the crest of the side gorge and several hundred feet down into it. Where they occur the solid strata beneath them are not scarped, but are beveled off to a moderate slope, allowing the tufa beds to repose upon them at an angle of about 23°. These tufas, apparently, were formed in the usual manner about the vent by the fall of lapilli and

fragments. It is clear that during the epoch of eruption a lateral valley had been excavated there; otherwise, the tufa could not be resting upon the slopes.

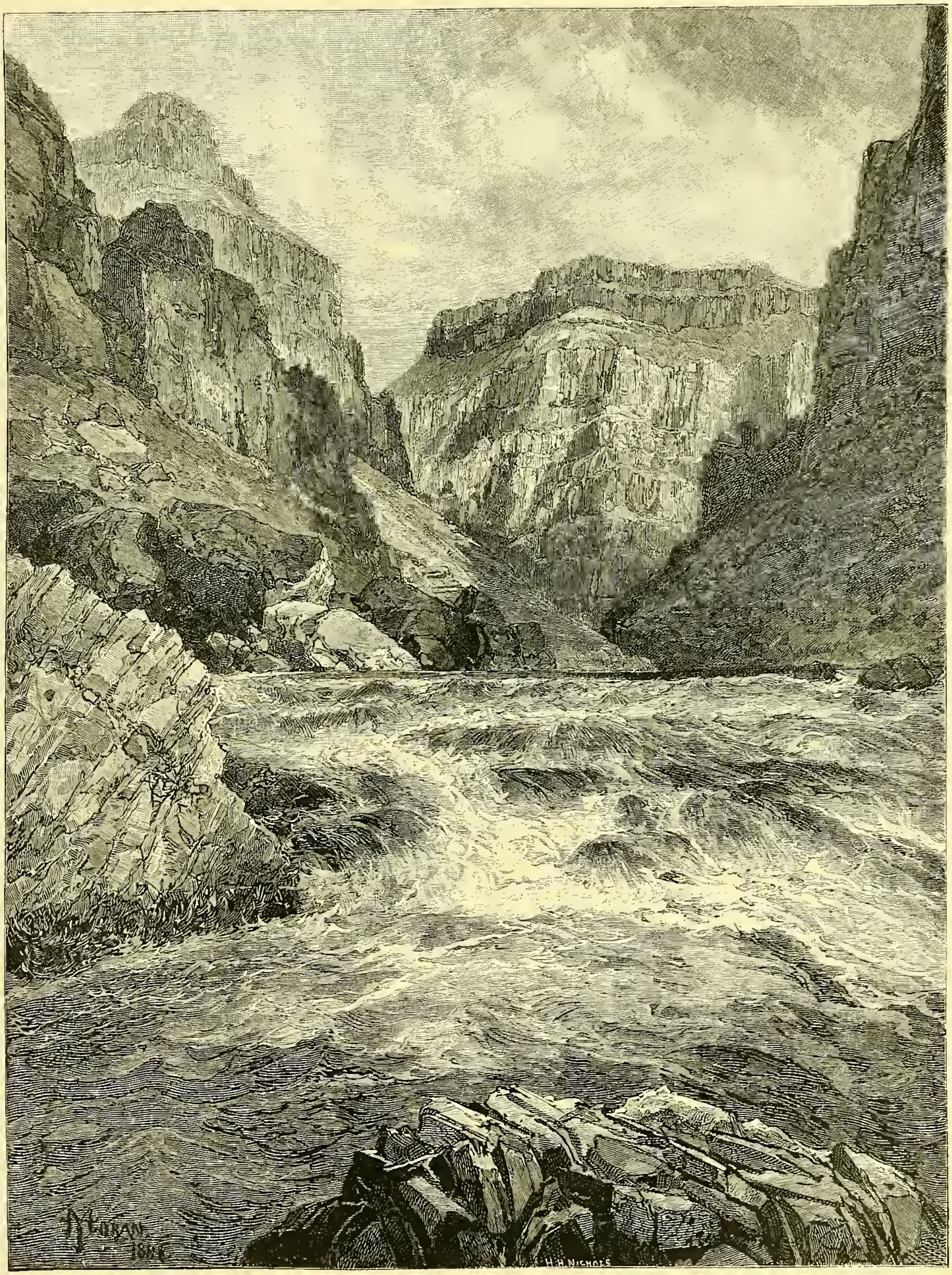
The depth of this valley was at least 500 to 600 feet. Between the dikes and the tufa, then, we find the limiting evidence which enables us to say very confidently that two-thirds to three-fourths of the present depth of the inner gorge has been excavated since the activity of that crater. As to the age of the crater itself, all that can be said is that it looks very recent. Except for the undermining of a considerable part of it by the recession of the great wall beneath, its preservation would be quite perfect. Still a nearer view might reveal evidences of antiquity which could not be discerned when viewed across the chasm from Vulcan's Throne, at a distance of nearly two miles. But, in any event, there is one conclusion most deeply impressed upon the mind: that this great inner gorge, vast as it is, has been excavated in a period of time which, judged by the geological standard, has been very short. The work has been done with a rapidity much greater than might otherwise have been supposed. The processes which have been so exceptionally active here are two—1st, corrasion, and 2d, the undermining of the wall of the inner gorge.

West of Vulcan's Throne there is a place where it is practicable to descend from the esplanade to the river. The way is difficult and at times well calculated to daunt the most active climber. The wall is here much broken down and the vertical face has given place to a very steep slope. The descent is upon the cascade of lava which has flowed down the Toroweap and poured into the abyss. Upon any ordinary rock the descent would be impracticable; but the roughness of the basalt gives admirable foothold, and there is no difficulty of a serious nature in passing the steepest places. The worst part is near the bottom, where the scouring of the river has left a nearly vertical wall 400 feet high. But there are several crannies where a precarious foothold may be obtained, and the river may be reached with less difficulty than might have been anticipated. Very seldom is it possible to descend in safety the walls of the Grand Cañon.

At the brink of the river there is little to call for special mention here. To the imagination must be left the task of picturing the aspect of the walls

of the inner gorge, rising 3,000 feet above us on either hand. The river now appears more nearly in its true dimensions. Its width varies greatly, being from 250 to 450 feet in width. Above and below us are cataracts where the water rushes with a deafening roar among huge blocks of basalt, and the voice of the waters is reverberated from the faces of the crags in a deep solemn monotone that never ceases. Between the cataracts the stream outspreads to great width and rushes swiftly by. It is almost always turbid, and generally is charged with a heavy load of sand and silt. On the lowest talus near the brink may be seen lines of high-water mark, some as high as fifty or sixty feet above the ordinary summer stages. Within those stages the rocks are ground and polished, carved into strange shapes, and worn by pot-holes from the scouring of the current. All of the bowlders are rounded and ground away, or have become carious and crumbly by the chemical reactions of air and water. All things plainly reveal the powerful effects of corrasion acting with extreme energy. We do not wonder at it now. The impetuous rush of the waters charged with sharp sand even at the lower stages is amply suggestive, and the mind is at a loss to conceive what must be the power of the river when its volume is many times multiplied.

The Toroweap Valley has a significance to the geologist which might not be at once apparent to the tourist. Even the geologist would be slow to discern it unless familiar with cognate facts displayed in the country at large bordering the Grand Cañon. In the effort to interpret its meaning it becomes necessary to take a hasty view of one or two broad facts relating to the lateral drainage of the chasm. Upon the north side there is but one side cañon carrying drainage from distant regions in all the distance between the head of the Marble and the foot of the Grand Cañons. This single exception is Kanab Cañon. In this respect the Colorado is much like the lower courses of the Nile; and the cause is plainly the same. The region is too arid to sustain any living streams or even to keep open the conduits which in former periods might have sustained them. Yet upon the assumption that at some former period the climate was much more humid all analogy compels us to believe that the Colorado once received many tributaries which are now extinct, and upon examination we find good evi-



THE INNER GORGE.—LAVA FALLS.—GRAND CAÑON.

dence that this was really the case. The Toroweap Valley is the modified channel of an ancient river. On the west side of the Uinkaret is another. A third is seen upon the south side of the Colorado, directly opposite the Toroweap, and a few others may be easily designated. It appears that all these rivers dried up before the inner gorge was excavated. For if they had continued to carry water we may be sure that they would have cut their chasms as deep as the Grand Cañon itself—just as the Little Colorado, Kanab Creek, and Cataract Creek have done. For we have only to look at the great multitude of lateral chasms of the upper courses of the Colorado and of its forks, the Grand and Green, to be deeply impressed with the fact that so long as a tributary river carries, we will not say a living stream, but even occasional floods, its channel will be scoured down to the same level as the trunk river itself. It is apparent, then, that the Toroweap dried up before the cutting of the inner gorge of the Grand Cañon began, and hence we infer that the arid climate which caused it to dry up existed before the beginning of the inner gorge.

By the application of other homologous facts, and by the same method of reasoning, we infer that the outer chasm has also been excavated during the prevalence of an arid climate. The platform of the country adjoining the cañon is at present devoid of lateral chasms, yet traces are often found of ancient channels which became dry at about the time the excavation of the outer cañon began, or very soon thereafter. They are cut to comparatively slight depths—from one hundred to three or four hundred feet. That they are not of recent origin is proved by the fact that they often have slopes away from the river, though it is clear that they formerly sloped towards it. In truth, the entire chasm betrays everywhere the continued action of an arid climate through the entire period of its formation. This arid period is limited, approximately, to Pliocene and Quaternary time. The general tenor of the facts is to the effect that the Miocene was a humid period and the Pliocene a dry one throughout the greater part of the West. This is one of the reasons which lead us to the very probable conclusion that the age of the Grand Cañon is not older than the beginning of Pliocene time. We might also draw a similar inference from a consideration of the enormous erosion which took place here before the excavation of the chasm was

begun. The denudation of the Mesozoic system was an incomparably greater work, and yet that denudation could not have begun until the last strata (the Lower Eocene) were deposited. If these inferences are well founded, we may assign the greater part of Eocene and the whole of Miocene time for the principal denudation of the Mesozoic, and the Pliocene and Quaternary for the excavation of the entire cañon. The proportion thus suggested between the portions of the work done and the divisions of time required to accomplish them seems very fair and reasonable. But the strongest evidence of all it would be almost impossible to recite here in detail. In general terms, it may be characterized as that internal evidence which appears when a vast array of facts, at first disjointed and without obvious relation, are subsequently grouped aright into a coherent system. Each constituent fact is then seen to admit of one intelligible interpretation and no other; and each subsidiary proposition has an overwhelming justification and an evidence of verity far stronger than any which could be summoned, if we endeavored to prove it independently.

CHAPTER VI.

THE UINKARET PLATEAU.

Common features of the Sheavwits and Uinkaret, with the latter as the type.—The boundaries of the Uinkaret defined.—The three groups of facts presented by the plateau, basaltic eruptions, the Hurricane fault, and the Permian remnants.—The foundation of the plateau is of Carboniferous strata, with many remnants of Lower Permian beds.—The volcanic masses.—Ancient basaltic plateaus.—The Trumbull, Logan, and Emma platforms.—View of the recent cones from the summit of Trumbull.—Grouping of the cones.—Their linear arrangement.—The lava caps of the plateaus.—Their antiquity.—Relations of the younger to the older basalts.—Former extensions of the lava caps and their denudation.—Similar facts presented by the Sheavwits Plateau.—The distribution of the younger basalts.—A long interval of repose between the old and young basalts.—Basaltic eruptions of very recent age.—The Hurricane fault.—Its appearance at the Grand Cañon.—Its northward extension.—Its great displacement at the Virgen River.—Distortion of the strata at the fault plane.—Details of the dislocation.—Action of the fault in the Queantoweap.—Relations of the fault to the lavas.—It cuts the ancient basalts, but not the recent ones.—Lava cascades across the fault-plane.—The Permian remnants.—Comparative smoothness of the denuded platform.—Infrequency of lateral drainage channels.—Base-levels of erosion.—Effect of an arid climate upon the topographical features—Geological history.

The two western subdivisions of the Grand Cañon district, the Sheavwits and Uinkaret Plateaus are much alike in their physical features and in respect to the groups of geological facts which they present. To study and describe both of them in detail would extend the discussion into a wearisome repetition without adding anything of sufficient value to justify it. The groups of facts which they present are displayed in a more compact, intelligible, and, on the whole, more complete manner in the Uinkaret than in the Sheavwits, and the former subdivision is selected for description in some detail as the representative of both. It will be necessary, however, to make frequent allusions to the Sheavwits.

The position of the Uinkaret is between the Sheavwits on the west and the Kanab Plateau on the east. For the most part, its boundaries are well defined. Throughout its entire western border the great Hurricane fault and the resulting cliff known as the Hurricane Ledge is the boundary; with equal definiteness the Grand Cañon terminates it upon the south. On

the northern side the Permian cliffs, there of unusual magnitude for that formation, constitute an unmistakable limit. Upon the eastern side only one-half of the boundary line is well marked. The Toroweap Valley serves this purpose very satisfactorily so far as it extends, but this valley fades out about 22 or 23 miles north of the Grand Cañon and thenceforward to the northern boundary there is hardly more than a nominal or even imaginary boundary separating the Uinkaret from the Kanab platform. Its length from north to south may be roughly stated at 45 to 50 miles, and its width at 8 to 12 miles. Of the four plateaus through which the great chasm extends it is very much the smallest. But in point of interest it is second only to the Kaibab.

The Uinkaret offers three groups of facts which are useful and important for our purposes. They are (1) Basaltic eruptions, (2) the Hurricane fault, (3) the remnants of Permian strata. They all contribute data which may be utilized in the discussion of the physical evolution and history of the region. No attempt will be made to draw from them any new light upon the general subjects of volcanism, displacement, or stratigraphy, for they present very little that is novel, and they could only serve to add a few more facts of no uncommon kind to categories which are already replete with observations of similar nature. They will be studied here solely with an eye to the main questions considered in this monograph—to find out what light they shed upon the physical history of the district. Thus considered they may prove to be of some value.

The foundation of the Uinkaret Plateau is the general mass of Carboniferous strata which everywhere constitute the platform of the interior spaces of the Grand Cañon district. Throughout the greater part of the Uinkaret are found many patches of Permian beds overlying the Carboniferous with apparent conformity. No doubt if the contacts were thoroughly exposed we should find many unconformities by erosion without any difference of dip. In a very few places contacts of this nature have been detected and under the circumstances they cannot well be regarded as exceptional, but should rather be looked upon as representing the ordinary method of apposition in these two groups of strata. These Permian remnants, with few exceptions, belong to the basal members of that series. They are the

so-called Permo-Carboniferous beds of King and Gilbert. But Mr. Walcott, finding their fauna more closely allied to the Permian, and, in fact, very strongly distinguished from or even contrasted with the true Carboniferous beneath, has wisely, as it seems to me, included them in the Permian of the Plateau Province as its basal division. Some conception of the manner in which the remnants of this formation occur may perhaps be gained by imagining a country which is nearly a smooth plain and only diversified by wide flat-topped eminences 80 to 150 feet high, separated by broad shallow valleys. Conceiving the strata to be everywhere horizontal the eminences would correspond to the remnants of Lower Permian strata, while in the valleys the summit of the Carboniferous is laid bare.

In the southern part of the Uinkaret there are several masses which are much more than low eminences, which in fact attain nearly or quite the dignity of mountains or at least of very large hills, and which preserve the entire Permian series with thick bodies of basalt overlying it. Two of these are especially noteworthy The loftiest and most conspicuous is Mount Trumbull, a broad, well-defined, and isolated mass rising nearly 2,000 feet above the plains at its base and nearly 3,000 feet above the Toroweap Valley near its southeastern flank. It consists of Permian strata which have here a thickness of probably 1,400 feet with a basaltic lava cap 500 to 600 feet thick forming the upper part of the mountain. In all strictness it is a great butte. Its strata are sensibly horizontal, and the whole mass has very plainly been carved out like a cameo by the denudation of the strata roundabout. Two or three miles southwest of Trumbull is Mount Logan, a tabular mass of much greater area but somewhat lower in altitude. In respect to structure, it is very similar to Trumbull, having nearly if not quite the whole Permian series, with a lava cap of varying thickness, but seldom exceeding 300 feet, and usually from 100 to 200 feet thick. South of Logan and distant about five miles is a platform which may perhaps be regarded as the continuation of the Logan mass in that direction. A depression exists between the two sufficient to warrant a topographical distinction if we desire it, though not so great as to destroy entirely the continuity of the two if we prefer that view of the case. This southern platform has apparently a structure similar to that of Trumbull and Logan,

though it is inferred that only a part and perhaps a small part of the Permian series is present while the lava cap has a thickness of 600 to 800 feet. Upon it stand a dozen basaltic cinder cones of comparatively recent origin, the largest and highest of which has received the name of Mount Emma. The same name will be used to designate the platform upon which that crater stands. To appreciate the significance of these tabular masses it is necessary to look at the distribution of the lavas of the Uinkaret.

BASALTS OF THE UINKARET.

If we stand upon the summit of Mount Trumbull we shall observe, in every direction, a multitude of well-preserved basaltic craters. In the course of a few hours, with the aid of a large field-glass, it is possible to descry from this point between 120 and 130 distinct cinder-cones, and there are many others which will escape detection. Altogether there are between 160 and 170 distinct vents upon the Uinkaret and its purlieus which have been observed and noted, and very likely some others have been overlooked. North of Trumbull the remotest one of the group is clearly defined at a distance of about 26 miles. Southward a cluster of them stands upon the brink of the upper wall of the Grand Cañon 16 or 17 miles away, and there are others beyond concealed by the cañon wall. Across the great chasm a few scattering ones may be seen nestled beneath the mighty southern palisade of the cañon. Eastward of the Toroweap eight distinct cones appear upon the nearer part of the Kanab Plateau. But it is around the base of Trumbull on all sides that they are huddled most closely together. In truth, they are so numerous in this vicinity that it is extremely difficult to count them, and we can never be sure that the counting is correct. None of these are of grand dimensions, and, in truth, most of them are very small. A few are of respectable size, attaining an altitude of 700 or 800 feet, and a diameter of a mile. Not one of them has yet been seen to contain any features of a novel character. They are all of the most ordinary structure, and are as much alike among themselves as so many ant-hills.

The grouping of the cones is not altogether capricious. The so-called

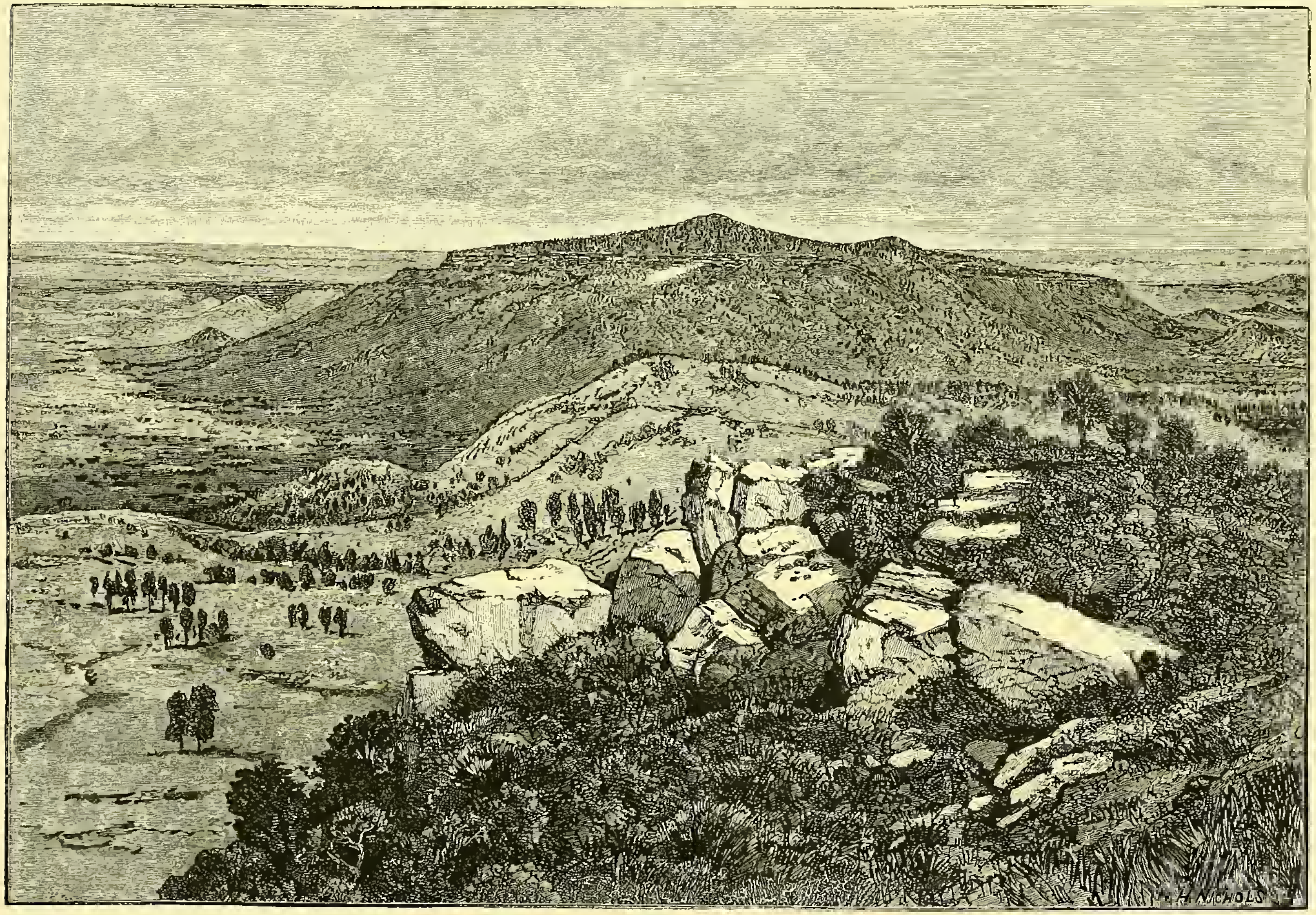
"linear arrangement" is often seen. From three to seven or eight cones may be found in rows, as if they were so many vents occurring along the course of a single fissure. Very many, however, seem too isolated in this respect. For aught we know, the fissure may be there, but only one vent is situated upon it. It may be remarked here that no evidence has been found on the Uinkaret that these vents have any association with fissures, beyond the mere fact that the linear arrangement is in quite a number of cases well marked. For example, on the Kanab Plateau, three or four miles east of the Toroweap, is a line of craters, seven in all, occurring at intervals of two or three miles. Each has around its base a few small *coulées* of basalt, but the country between them is in greatest part free from lava. There is no trace of a fault or fissure visible there. A fault of any notable magnitude could not escape detection, and a fissure, if it exists there, has been wholly concealed The same is true of the other lines of craters. Although the intervals between them are frequently free from lava, and the edges of the Permian beds well exposed in many of the shallow vales, no trace of such a fracture has yet been seen. Still, the fissures may be quite small—only a yard or two in width—and they may have been covered so effectually by alluvium that they have escaped observation. The basalts here show no tendency to seek the great fault planes as favorite places from which to erupt. I am inclined (with some reserve) to remark that they rather avoid such places, or resort to them less frequently than to others. There are very few cases where the crater seems to be very nearly or exactly upon the line of a great fault. Vulcan's Throne, at the foot of the Toroweap, is such an one, and four or five other instances have been noted. The strongest feature of such occurrences, however, is their paucity. If there be any specially favored *locus* of eruption, with reference to a great fault, I should say that it may be found along the upthrow of the fault, and from a mile and a half to four or five miles from the plane or line of dislocation. While exceptional cases are found, they are very uncommon.

The heavy lava caps which form the summits of Trumbull and Logan, and the platform on which the crater Emma stands, have nothing in common with the craters just mentioned. These basalts did not come from such craters, but are much older. The vents from which they issued have been

completely demolished by time and decay. The existing cones are, geologically speaking, of very recent creation, even the oldest of them. The eruption of the basalts in the lava-caps goes back to an older period, when the country presented a different aspect from the present one. These ancient lavas form in reality "basaltic plateaus" similar, in most respects, to those of the Auvergne and Vivarais Mount Trumbull itself is such a plateau essentially, though its horizontal dimensions are greatly shrunken in comparison with their former magnitudes. The older lavas are much more massive, and lie in thicker sheets, than any to be found among the younger eruptions. Lithologically, there is no difference among them. Old and young seem to be of identical constitution, and, in truth, it seems as if every *coulée* on the Uinkaret might have come from one and the same vesicle.

The point to be specially noted in connection with these older basalts is that they are found upon the summits of the highest tabular masses, while the younger basalts, as a general rule, occupy the lower surrounding spaces. This is admirably shown in Mr. Holmes' panorama from Mount Emma (Atlas sheet No. IX). On the left is shown the tabular mass of Logan, which is capped with ancient basalt, without a single recent cone or lava-flow upon it. In the middle of the picture is Trumbull, the loftiest of all, crowned with its old lava-cap. On the nearest corner of the mountain there is a solitary crater of much younger date, sending heavy streams of basalt down to the plain below. The profile of this crater is also well shown in the wood-cut (Plate XX), where it is represented on the right-hand flank of the mountain as it appears from the summit of Logan. The younger age of this crater is betrayed at once by the fact that its lava streams are shot down across the abruptly scarped edges of the old lava-cap and across the eroded edges of the underlying strata.

The Emma platform is also an ancient basaltic plateau. But while Trumbull contains only one recent crater, and Logan not even one, there are a dozen or more on the Emma platform. It is evident, however, that they are much more recent than the main lava-cap; for they have many streams of basalts proceeding from them, which can be easily distinguished from the more massive flows beneath. The streams which came from those cones which stand near the western brink have poured down the western



MOUNT TRUMBULL.—FROM MOUNT LOGAN.

escarpment of the Uinkaret across the branches of the Hurricane fault, and have reached to the bottom of the Queantoweap Valley, more than 3,000 feet below. These *coulées* lie across the scarped wall of the old lava-cap, which had been greatly eroded and wasted before the younger floods were outpoured. The relation of the younger basalts of the Emma platform overlying the older ones is therefore exceptional, as compared with the relations of the two groups of lavas presented in Trumbull and Logan.

The inferences to be drawn from these facts are as follows. During the eruption of the older basalts the Uinkaret Plateau had a very different topography from the present. It is probable that at that epoch very large bodies of Permian strata, some of them embracing the entire series, remained, and not only covered the greater part of the plateau, but may have sustained important remnants of the Trias. It is useless to speculate as to details, or even as to the broader features of that ancient topography. The conclusion is limited to the inference that the Permian formation then constituted the general platform in much the same way as the upper Carboniferous now does. It is a fair presumption that the plane of contact between the lava-caps of Trumbull and Logan, and the Permian beds beneath, represents the approximate geological horizon which then constituted the surface of the region. In one place higher strata may have occurred, in another some progress may have been made in the denudation of the Permian. The remnants of this formation, now found in Trumbull and Logan, owe their preservation to the thick coverings of basalt.

On the Sheavwits Plateau we find a precisely similar state of facts. About 12 or 15 miles northwest of Logan is a large remnant of Permian beds overlaid with basalt. It has received the name of Diamond Butte. It rises 800 to 900 feet above the surrounding plain, and discloses the edges of the strata lying almost horizontally and showing their characteristic colors. Far beyond it, in the northern part of the plateau, may be discerned the cliffs bounding the principal mass of this formation. Turning to the southeast of Logan, we may perceive a much larger mass of the same nature situated in the southern part of the Sheavwits. It consists of Permian strata covered with basalt. The length of this outlier is about 25 miles and its width from 3 to 6 miles. Whether the entire Permian series is

present in these insulated mesas of the Sheavwits we do not know, but we are quite confident that much more than half of it is there. The meaning of these outliers is evidently the same as that which we have deduced from the plateaus of Trumbull and Logan. The Sheavwits basalts were erupted at an epoch when the Permian formed the general surface of the plateau, and these outliers have been preserved by the lava sheets from the denudation which has removed the unprotected portions. (Plate IV.)

We may now revert to the younger basalts. These have all emanated from cones which still remain in good preservation. Very few of the craters have suffered any extensive ravage from the chemical processes of secular decay or from the mechanical work of erosion. But now and then we find one which has been sapped, battered, and dissolved to some notable extent, though never to such an extent as to efface its more important features, or as to leave doubt about its nature and character. As already remarked, these cones cover a large extent of ground, being found from the brink of the chasm northward throughout a space of nearly 50 miles, and from the western verge of the Uinkaret to a point 20 miles east upon the Kanab Plateau. All around the base of Trumbull, and thence southward over the extreme southern part of the plateau, they cluster most thickly, often standing base to base, or even with confluent bases. Many of them have multiple vents or cups, and four or five vents in the same pile are not uncommon. As we proceed northward or eastward from Trumbull the cones gradually become less frequent and more scattered.

The lava streams which have flowed from these cones are never very voluminous, compared with what may be seen in more extensive volcanic regions. On the southern part of the plateau some copious eruptions may be seen. But it is very difficult here to distinguish one eruption from others. In numerous places we find lava flows from a mile to two miles wide, and reaching five or six miles from the vents; but there can be no doubt that they are composed of very many streams—perhaps hundreds of them. And yet it is impossible to separate any one stream in its entirety from the others. In many places the basalt has run over the edge of the plateau to the bottom of the Toroweap, to the esplanade of the cañon, and to the floor of the Queantoweap Valley on the west. The passes where these lavas have

descended form very striking and suggestive spectacles. Each of them holds many streams, but so blended together in appearance that they might at first glance be supposed to be each a single *coulée* of vast proportions. There are five of these passes descending into the Toroweap; two from the southern end of the Uinkaret to the esplanade of the cañon, and two descending into the Queantoweap. The largest of all is upon the western side of the Uinkaret, leading down into the Queantoweap from a cluster of large cones standing in the interval which separates the Logan from the Mount Emma platform. This lava cascade is about two and a half miles wide and descends about 2,600 feet.

Among the basalt fields which lie north and east of Trumbull there are two which attain notable proportions. One of them begins about two miles north of the mountain, and has at its summit a multiple cone consisting of five or six vents. This cone has been considerably wasted by erosion, and its interior structure is in great part laid open to view. It shows the familiar arrangement of tufaceous and scoriaceous material around a central pipe, the layers dipping downwards and inwards from the rim of the crater towards the pipe, and downwards and outwards from the rim towards the base. The anatomy of the multiple mass is also shown, and the growth of new craters upon the cone previously formed. From these vents a great number of eruptions have taken place, and they have built up a turtle-shaped mass of lavas having a thickness of 700 to 800 feet, and spreading out to the north, the east, and the west of the cone four to six miles. Towards the borders of this field the thickness steadily diminishes and at last vanishes in a thin irregular edge. East of Trumbull is another and somewhat larger field. This has many large cones upon it, standing in clusters of three to five, arranged in a line. The largest individual *coulées* seem to have emanated from these craters, and their aggregate thickness may exceed 500 feet. In the outer portions of the volcanic area the lava fields are all of small extent and usually very thin. From the cones on the Kanab Plateau the eruptions have been of very small volume and the lavas do not extend more than half a mile from their bases.

Between the epoch of the extravasation of the ancient basalts of the Trumbull, Logan, and Emma platforms and the epoch of eruptions from

the cones, it is evident that a long period of time elapsed. The ancient basalts are much eroded. Not only have their craters been demolished, but the massive floods which emanated from them have been greatly wasted. That these lava-caps are mere remnants of masses covering originally much broader areas is quite apparent. Their very aspect speaks strongly in favor of this conclusion. The surfaces of these basalts are gray with weathering, and the chemical action of the atmospheric agents has penetrated deeply into the most massive portions. None of them have preserved any of those rough, inflated, ropy, scoriaceous matters which form the surface of every fresh outpour. Nothing is left but the most compact and solid portions of the lava sheets. At the borders of the tabular masses which they cover they end in cliffs, where the thick beds of lava are suddenly cut off by the undermining and recession of the strata beneath them. Large gorges and amphitheaters are excavated into the flanks of those tables into which the lava-fragments have fallen as the caps were undermined. No such devastation has wasted any of the younger lavas. These are much fresher in appearance and often as black as coal. Only around the outermost edges of these sheets do we find any traces of undermining and degradation. Almost all of them still preserve those slaggy, spongy, and scoriaceous products left by the viscous stage of cooling.

There are many indications that a long interval of quiescence separated the two epochs of volcanic activity, some of which will appear in the sequel. Here we may mention merely that none of the eruptions hitherto seen appear to have taken place under circumstances which leave any doubt as to which of the two epochs they belong. And surely no notable masses of any age whatever have escaped observation. In that long interval of quiescence important changes took place involving a large amount of erosion and a large amount of displacement, and these changes have left their marks which cannot be mistaken.

Nevertheless, the younger period of eruptions was a long one; so long in fact that it is a fair question whether, for purposes of convenience, we may not subdivide it artificially, giving to the earlier outbreaks the designation of middle-aged eruptions and to the latest that of modern eruptions. But it should be done with the understanding that the most ancient of all

the lavas—the basalts in the lava-caps—form a group by themselves wholly apart and distinct from all the others and with a great and well-marked interval between; while the so-called middle-aged and modern eruptions shade into each other without any such distinction.

In those volcanoes which may thus be termed middle-aged we find evidences of considerable progress of the decay which must ultimately remove them altogether. The cones are still standing, indeed, but are wasted and worn. Their flanks are channeled deeply with ravines, and in some of them the interior structure is dissected and well exposed. The cinders and scoria have been converted into soil and the fragments have lost all resemblance to their original aspects. The lava fields around them have also put on an appearance of antiquity; not so great indeed as that of the massive sheets in the lava-caps far above them, but yet plain and conspicuous. They have become gray and dull in color, and the decomposition of the augites and feldspars has penetrated to notable depths into the solid blocks. Such are the cones and lava fields of the turtle-back which lies immediately north of Trumbull, and such are the masses which extend from the base of the mountain eastward.

Let us now look at the other extreme—the extreme of recency. Between Logan and Trumbull we find some rather extensive fields of basalt, which excite surprise when we first come upon them. They are hidden by a surrounding forest of large pines, and the first view is gained either by finding ourselves within a dozen yards of the border, as we wander through the forest aisles, or else by a sudden *coup d'œil,* as the whole expanse flashes upon the vision from the summit of Trumbull. It looks as fresh as any *coulée* of Vesuvius ejected twenty or thirty years ago.* Compared with the other later eruptions of the Uinkaret, its dimensions are larger than the average. Its entire surface is covered with blocks of pumice of the most delicate kind. It has a texture very much like the lightest coke, the vesicles, however, being considerably larger than those of ordinary coke, and very uniform throughout. The septa between the vesicles are very thin, and the whole mass is so light that when a specimen is varnished over to

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*Such was the opinion of Mr. Holmes, who viewed it with me, and who had just returned from a visit to Vesuvius.

prevent access of water to the cavities it floats upon water like a cork.* In this condition the lava is extremely susceptible to weathering. It quickly turns gray or rusty, and dissolves into soil. But in this lava field the most delicate pumice is still intensely black, and only here and there may be found specimens which begin to show the gray. (Plate XXI.)

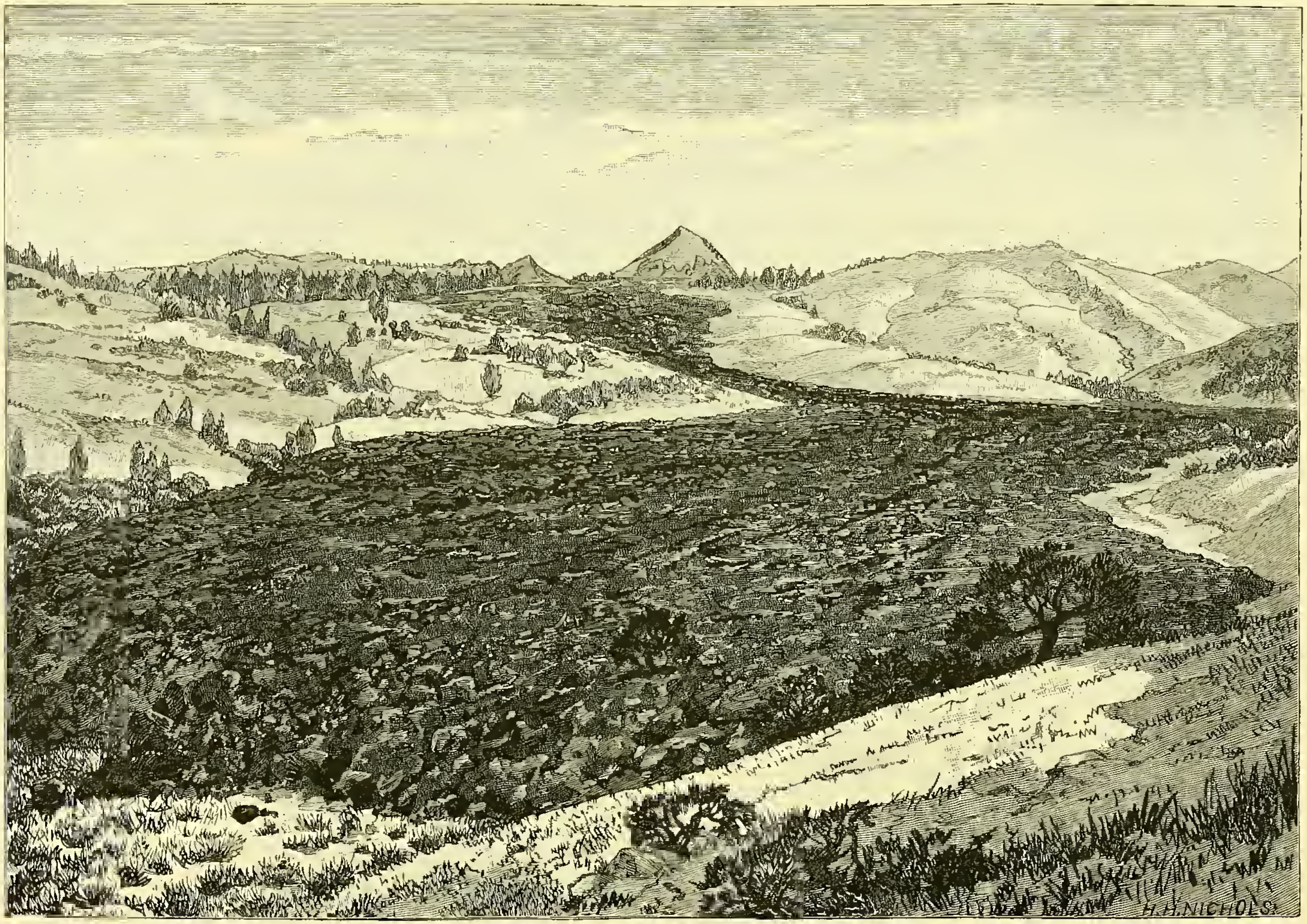
Any attempt, however, to fix the age of these lavas must prove quite fruitless. All that we can say is that it is very recent, even when time is judged by the historic or human standard. It cannot be many centuries old, and it may be more recent than the Spanish conquest. But there are reasons why lavas should here preserve for centuries the freshness which is lost in other countries in as many decades. The climate is arid, and there can be no question that the chemical action of the meteoric agents upon the lavas proceeds here with extreme slowness.

Between the oldest of the middle-aged eruptions and this modern outpour we find lavas of all intermediate ages. No long period within those limits appears to have passed without witnessing the activity of some one or more of the many cones now standing.

THE HURRICANE FAULT.

We turn now to the great displacement which forms the western boundary of the Uinkaret. Of all the great dislocations of the western mountain region there is surely none more wonderful or more interesting. Its full extent is not yet known, but the greater part of it has been well studied. We do not know, as yet, where the southern end of it is located, or in what manner it runs out, whether by merging into the great displacement of the Aubrey Cliffs, or by gradually vanishing in the sierra country of Arizona. We know, however, that it appears in the Carboniferous platform south of the Colorado, and that it extends 30 or 40 miles in that direction without undergoing any great modification of the features it presents where it crosses the river. This portion of it, however, has not been ex-

* It may be remarked here that this basaltic pumice differs from ordinary rhyolitic pumice, the latter usually having very elongated or tubular vesicles, while the vesicles are seldom drawn out in the Uinkaret basalt, but are nearly round or polyhedral.



RECENT LAVA FLOW ON THE UINKARET.

plored in detail, and it is premature to attempt any further account of it. In the southern wall of the Grand Cañon it appears with a displacement of about 1,500 feet, throwing down the whole country to the west of it, and producing a great cliff of displacement, which vanishes away into indefinite distance beyond the river. As we look at it from the northern side it is seen that the beds on the side of the downthrow flex downward as they approach the fault-plane. This feature is a very common one in the faults of the Grand Cañon district, and will repeatedly recur as we trace them. Its effect just here is to make the displacement at the fault-plane much greater than at the distance of a mile or two to the west of it. On the north side of the cañon the fault appears in still greater magnitude, and also branches out into four distinct displacements, appearing at rather small intervals. As far north as Mount Logan this multiple character is preserved, but about 4 miles further north the branches disappear, and the dislocation becomes a single fault, with the edges of the dropped beds turned down. There is a slow but steady increase in the amount of displacement as it extends northward, until about thirty miles north of Logan the increase becomes more rapid. As we approach the Virgen River the dislocation becomes very great. Upon the sunken side the Permian makes its appearance, then the Trias, and finally the Jurassic sandstone, so that near the Virgen we stand upon the summit of the Carboniferous on the lifted side of the fault, and look down upon the Jura, 1,200 feet below us at the base of the cliff. Here the estimated shear of the fault is about 6,600 feet. North of the Virgen the shear increases rapidly, until ten miles north of the Virgen we find the lower Eocene on one side and the Carboniferous nearly a thousand feet above the Eocene on the other. The displacement here is difficult to estimate with accuracy, but it probably exceeds 12,000 feet, and may attain 14,000 feet.

In view of the great dimensions here inferred, there is a necessity for great care in scrutinizing the facts, and for ascertaining whether there is no other interpretation. This conclusion involves the assumption that the entire Permian and Mesozoic series, as well as the local Eocene, are present in the stratigraphic column of the thrown beds. Of this there can be little doubt. As we come northward along the fault we find the beds of the several groups coming in one after another until we reach the Eocene. In

some places they are partially obscured by volcanic sheets, but enough of them is exposed to leave no doubt as to their presence. Moreover, they all exhibit a much larger volume than the corresponding exposures further eastward. Unless we suppose that the inferior formations thin out or disappear as the superior ones come in, the inferred amount of displacement is an unavoidable conclusion. There is no apparent reason for such a supposition, and the presumption is quite the contrary.

Although it is going far outside of our district, it may be remarked that the Hurricane fault extends northward into Utah along the entire western front of the Markágunt, and is still apparent on the southwestern flank of the Tushar range, where it finally disappears beneath great floods of lava. Its total length is certainly more than 200 miles. Wherever it runs it always forms an important topographic feature, the prominence of which is generally proportional to the amount of displacement. At the maximum part it constitutes the border of the great Markágunt mass, and at the same time the border of the Plateau Province. Between the Virgen and the Colorado it is the dividing line between the Uinkaret and Sheavwits. At the upthrow is the Hurricane Ledge, which looks down 1,200 to 1,600 feet upon the Sheavwits platform. The cliff of displacement thus formed is perhaps the longest and best defined and one of the loftiest in the West.

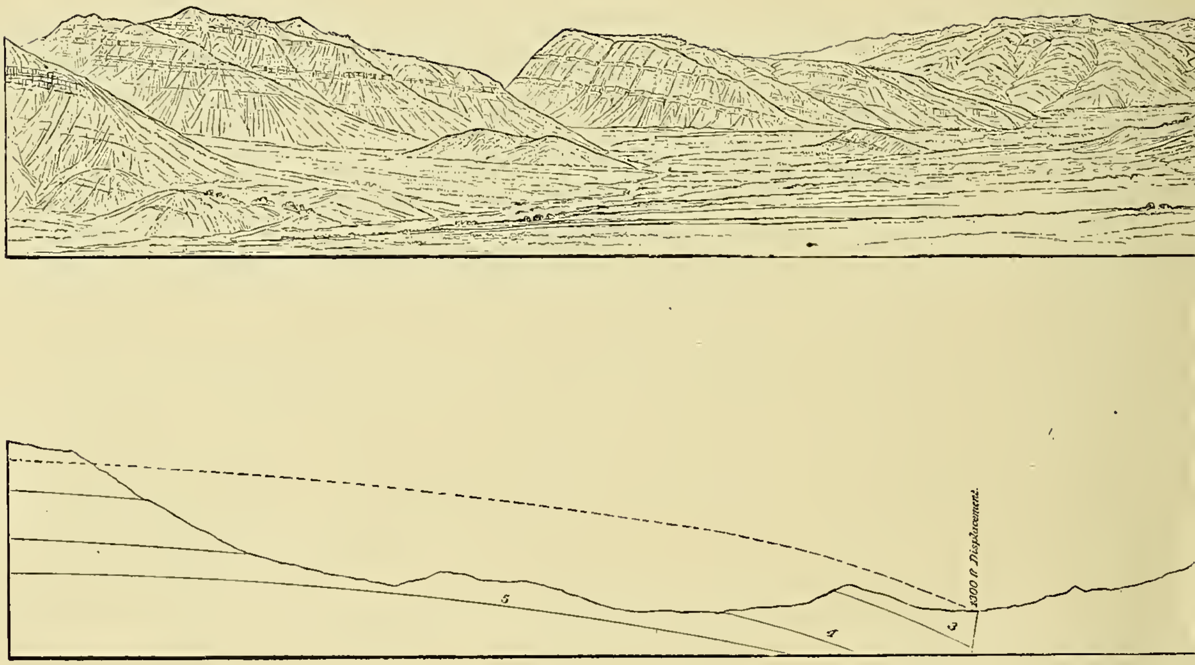
The details of this displacement are full of interest, and they are also extremely varied. The portion which lies along the greater part of the Uinkaret border is generally not very complicated, but in a few localities it is extremely so. From fifteen to twenty miles south of the Virgen the Sheavwits platform in the vicinity of the fault plane is terribly shattered and mangled, and it is doubtful whether any analysis of it here is practicable; but the simple character is soon resumed, and thenceforward to the Colorado every phase of it is distinct. It presents a single sharp dislocation, with no apparent crushing or shattering of the beds, and the only noteworthy feature is the persistent way in which the beds of the downthrow flex downwards as they approach the fault line. In many places, also, the beds of the upthrow flex upward a little for a few hundred yards as they approach the fault, but this feature is somewhat less pronounced and less persistent than the opposite flexures of the dropped side. It is interesting to note here that

the downward flexure has insured the preservation of a narrow strip of the Permian beds at the base of the Hurricane Ledge. The normal profiles produced in the cliff by erosion are such that the Permian strip receives protection from the talus. The explanation of this peculiar arrangement may be as follows. We may suppose that before the fault was started the beds along its course had been bent into a monocline dipping to the east. Such monoclines are the commonest and most typical form of displacement in the Plateau Country, and, though it would be out of place here to discuss the matter at length, I suspect that they are much more common in other regions, especially in little disturbed regions, than is generally supposed. The existence of such a flexure would leave the Sheavwits platform much higher than the Uinkaret. We may suppose the Uinkaret to have been hoisted above the Sheavwits after the formation of the flexure, or, in brief, that the flexing of the beds antedates the fault. This seems very simple, and natural enough, nor does any other explanation suggest itself; but this identical feature is repeated over and over again in other lines of displacement. It is seen in the southern part of the great Sevier fault at Pipe Spring, in the West Kaibab fault, and in numerous places along the great dislocations in the terraces and High Plateaus. If the explanation be a true one, it thus assumes a high degree of interest. Powell has long since remarked the homology between faults and monoclinal flexures by showing that they often shade into each other; but in such cases the shearing couple has the same movement, whether the displacement be flexure or fault. In the Hurricane the movement of the shearing couple in producing the monocline is reversed in the formation of the fault.

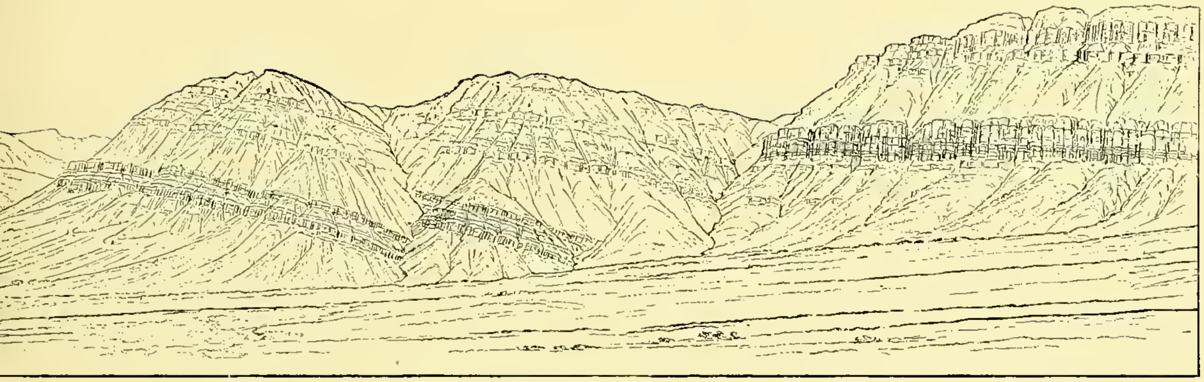
Let us now look at the features which the Hurricane fault discloses along those portions of the Uinkaret which have been the scene of volcanic activity. These are admirably revealed in the Queantoweap Valley. This valley is almost the exact counterpart of the Toroweap, repeating the features of the latter with singular accuracy. It is a lateral valley excavated upon the sunken side of the Hurricane fault, and cuts through the upper and most of the lower Aubrey groups of the Carboniferous, and opens upon a wide esplanade of the Grand Cañon, just as the Toroweap does. The inner gorge of the cañon, however, is much less profound here; the espla-

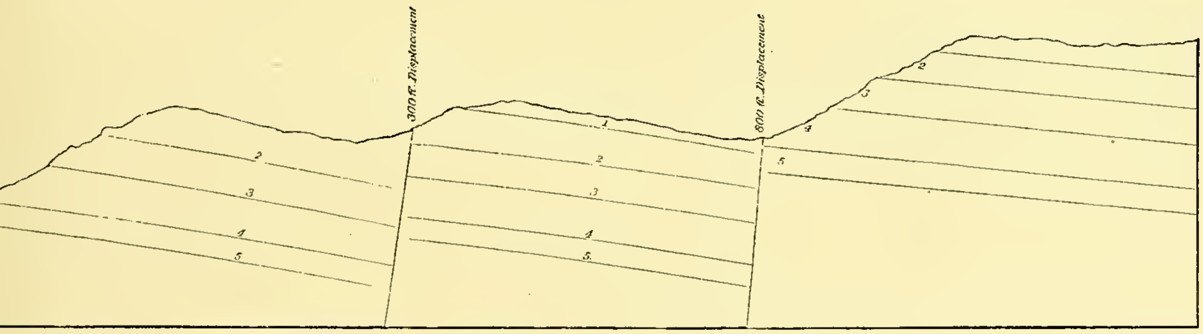
nade lies at a much lower level, and the floor of the Queantoweap is a thousand feet lower. All this arises from the action of the fault, which carries down everything to the west of it from 1,200 to 1,800 feet. From the heights of the Uinkaret two great lava cascades descend into the valley, each composed of innumerable floods, which are so intimately blended together that at a hasty glance they look each like a single mighty outflow. The southern cascade emanates from a group of cones, of which Mount Emma is the central and dominant pile. The northern cascade, which is wider, but probably contains less mass, descends from a line of large craters which stand upon the brink of the plateau between the Logan and Emma platforms. We may descend either of these cascades with ease, but the northern one is to be preferred. Reaching the bottom of the Queantoweap, and following its course downwards until we reach the southern cascade, we turn about and, looking northward, observe the features depicted by Mr. Holmes in Plate XXII. Three branches of the Hurricane fault are very plainly indicated. The high cliff on the right conceals the heights of the Uinkaret above and beyond, but by changing our standpoint there is no difficulty in recognizing back of this cliff a fourth branch of the fault, having a displacement of about 500 feet. Having fixed these dislocations, we may now return to the lava cascade and ascend to the plateau, noting on our way the relations of the lava to the faults. We find that the basalt has not been affected by them. The faults were there before the eruptions took place, and the lava descending into the valley flowed across them, molding itself to whatsoever features the faults and subsequent erosion had generated; nor can we detect any trace of shearing in the lava beds. It must be observed, however, that the lavas in this cascade are all very young, belonging, without exception, to later eruptions. It is doubtful, even, if they belong to those which I have termed middle-aged eruptions, and this term I have used to designate the earlier portions of the more recent outbreaks. They are certainly more recent than those which lie north and east of Trumbull.

Following the branches of the fault north and south, we at length find two of them cutting along portions of the Uinkaret flank, where remnants of the more ancient lava caps are preserved. Here the faults cut the lavas. This is plainly seen on the northwestern flank of Logan and again imme-

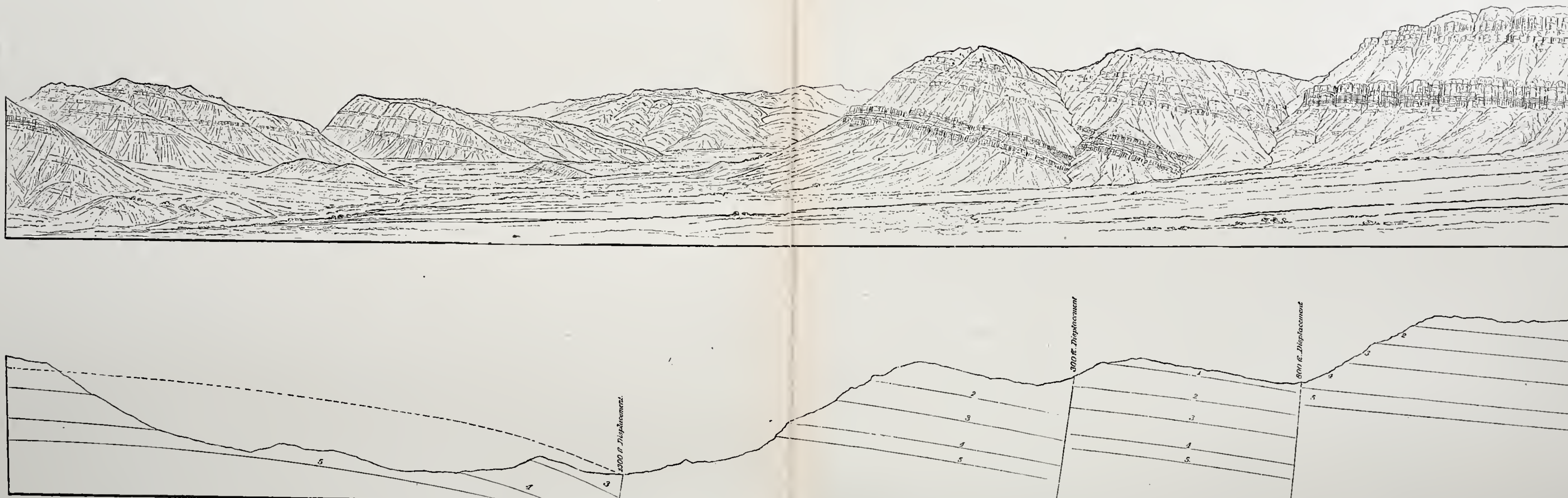


THE HURRICANE FAULT





IE QUEANTOWEAP VALLEY.



THE HURRICANE FAULT IN THE QUEANTOWEAP VALLEY.

diately west of Emma. And what is more, the basalt appears to have suffered the full amount of shearing due to the branch of the fault which cuts it. The largest branch is the westernmost, and it does not appear to run among any of the older basalts, so that we cannot venture any inference concerning the age of this branch relatively to the older basalts. But in general we have positive proof that two of these branches were formed after the ancient eruptions and before the recent eruptions. Here is an important fact, for it lets light in upon the dark and difficult problem of the age of the great Hurricane displacement, and this problem forms an important link in the discussion of the history and physical evolution of the cañon and the region which adjoins it. This fact will be followed to its consequences very speedily.

It still remains to consider whether all these branches are contemporaneous. It at first seems possible that they may be of widely different ages. I know of no crucial fact which may be relied upon to prove that the several branches were formed together, but on the other hand there is a strong presumption that they do not differ much in age. Wherever we find the true position of the main fault, we observe that it lies close to the base of the ledge. The amount of recession by erosion of the cliff of displacement is very small. Hence we infer that this cliff is of comparatively recent origin, and, as the branch faults are proven to be recent also, the separation in point of time cannot be very great.

THE PERMIAN REMNANTS.

The discussion of general questions of stratigraphy is not contemplated in this work, except to such extent as may be necessary to throw light upon the principal problem of which it treats—the Tertiary history of the Grand Cañon district. There is, however, so much interest to be found in the study of the remnants of the Permian which are scattered over the Grand Cañon platform that it seems proper to mention them somewhat more fully than the principal theme may require.

The interior spaces of the district have hitherto been spoken of as being

floored with the summit members of the Carboniferous strata, patched with remnants of the Permian. A somewhat more precise account of its surface geology may be given. Adverting first to the topography, it may be remarked that, in general, it is very mildly undulated. The great chasms which enter the Grand Cañon are very few and far between, and so also are the great cliffs of displacement. These grand features occupy in reality but a small portion of the entire area, and are limited to narrow winding strips. Between the lines of diversification by cliff and cañon, the vast expanse is only very gently undulated for the most part, though here and there a few notable masses rise above the plains to considerable altitudes. Throughout this broad and slightly varied expanse the surface of denudation cuts the strata in such a way that the hills usually consist of lower Permian strata lying horizontally, while the shallow valleys expose the Carboniferous. The mean position of the surface of denudation is very nearly coïncident with the dividing horizon between those two formations. But as that surface is an undulating one and the strata are sensibly horizontal, it sometimes rises a little above that dividing horizon and sometimes falls a little below it. If, however, we successively visit districts considerably apart, we shall find in one of them that the mean position of the surface of denudation is below that horizon so far that no Permian rocks appear in the hills; in the other it is so far above it that no Carboniferous rocks appear in the valleys.

Upon reflection, we cannot fail to be struck with this remarkable fact, that an area so extensive has been denuded in such a manner that the surface of the country is everywhere very nearly the same geological horizon. The fact becomes all the more striking when we recall, first, the enormous denudation which has taken place; second, the great altitude of the country; and, third, the very considerable inequalities of altitude. The fact is at variance with what we usually find under the circumstances here recited. A high country, greatly ravaged by erosion during a long succession of geological periods, would, we should think, be carved deeply by valleys with rugged, lofty, and highly irregular masses between; and when displacement by faults and flexures and by the tilting of broad expanses is added to the various conditions, we should expect to find these irregularities still

more complex. The comparative smoothness of the Grand Cañon platform, therefore, is a problem which seems to demand special explanation. Such an explanation may, I think, be given, and in the sequel it will be offered. Just here it may be sufficient to indicate it only in the briefest manner.

We may suppose that this entire region, at the epoch at which the great denudation of the Mesozoic system approached completion, occupied a level not much above the sea. Under such circumstances it would have been at what Powell terms base-level of erosion. The rivers and tributaries would no longer corrade their channels. The inequalities which are due to land sculpture and the general process of erosion would then no longer increase, and the total energy of erosion would be occupied in reducing such inequalities as had been previously generated. During periods of upheaval, and for a considerable time thereafter, the streams are cutting down their channels, and weathering widens them into broad valleys with ridges between. The diversification so produced reaches a maximum when the streams have nearly reached their base-levels. But when the streams can no longer corrade, and if the uplifting ceases, these diversifications are reduced and finally obliterated. Such, I conceive, was the case here. Somewhere about the close of the Miocene the principal denudation had been nearly completed. The Grand Cañon platform then may have lain near sea-level, and the remnants of Mesozoic beds which we may imagine to have been scattered over it were gradually obliterated, and the entire region was planed down to a comparatively smooth surface. Subsequently a new epoch of upheaval set in, and the Grand Cañon was begun. Under an ordinary climate this new upheaval would have set at work an intricate plexus of streams, carving out anew the uplifted platform into deep valleys and lofty ridges and mesas. But a new condition intervened. The climate had now become an arid one. There were but few streams to corrade, and as the aridity increased these few became only three or four along the entire drainage system of the Grand Cañon platform. No new inequalities were generated other than those we now see, because there were no rivers to carve them out.

This explanation may seem at first to be a gratuitous assumption for the explanation of a single fact. But as the discussion proceeds we shall find ourselves brought frequently to the inference of an epoch when the

climate passed from a humid to an arid condition, and of two or more epochs when a throe of upheaval followed a considerable period of repose. And the presumption will grow stronger, and at last become very powerful, that this change of climate and one of the throes of upheaval, the birth of the present Grand Cañon, the most ancient basaltic eruptions of the Uinkaret and Sheavwits, and the starting of the greater faults of the region, were not only contemporaneous events, but were mutually associated and interdependent.

The facts which have been recited in this and in the preceding chapter seem to me to indicate the following order of sequence in the events which have resulted in the production of the Grand Cañon. At the close of Miocene time the larger part of the general denudation of the Mesozoic strata had been completed. Considerable masses of the Permian were then remaining, which have since been eroded. At that time the surface of the country was situated at a level not far above the sea, and was at a base level of erosion. It had been so for a long stretch of time, sufficient, in fact, to have allowed of the obliteration of most of the inequalities which had been generated by the upheavals and erosion occurring in late Eocene and early Miocene time. At length a new epoch of upheaval set in, hoisting the country from 2,000 to 3,000 feet, and somewhat unequally. Under ordinary circumstances this would have resulted in the production of fresh features by the corrasion of streams. But a change of climate from moist to arid had in the meantime occurred. The streams were in chief part dried up, leaving only the Colorado and a few of its more powerful tributaries. Such streams as remained alive corraded their channels, but the greater part of the platform suffered no other havoc than the slow waste by sapping of the edges of the Permian remnants in much the same manner as it does at the present time. Contemporaneously with the upheaval the Hurricane fault was developed. Possibly some form of displacement of much less magnitude than that now existing was already established; possibly only a part of the present displacement was effected during this particular throe of upheaval. Accompanying the uplifting and faulting movement were the earliest volcanic outbreaks, represented by the lava caps of the Trumbull, Logan, and Emma platforms. At length the uplifting action paused for a

time. The volcanism ceased to be active. The river sought and quickly found a new base-level at the horizon of the great esplanade of the Grand Cañon. In its turn the process of corrasion rested. The process of erosion during this second period of base-level was occupied in the only work possible under the circumstances, viz, sapping the newly-formed cliffs of the cañon. The cliffs, thus attacked, receded away from the river, gradually developing the broad avenue of the outer chasm. In the very few tributaries which survived the advent of the arid climate the same process of sapping and recession of cliffs is discernible. When the cliffs of the outer chasm had receded from two to three miles away from the river, another and more active period of upheaval set in. Again the country was hoisted, this time more than before. At once the corrasion of the river bed was renewed. The faults were increased. The volcanic fires were rekindled. Swiftly the inner gorge was scoured out, and the chasm assumed its present condition. At present the uplifting force is inactive, the volcanoes are extinct, the faults are not increasing, and the river has nearly but not quite reached another base-level.

Throughout the entire stretch of the Grand and Marble cañons this order of events is betrayed. It is not confined to the Uinkaret and Toroweap, but is general for the whole district. The theory fits the facts perfectly, and the range of facts to which it is adapted is a very wide and complex one; for it comprises the drainage, the surface topography, the erosion, the volcanism, the displacements, the climate. All these facts and their respective trains of phenomena the theory brings into harmony, and it shows their relations to each other. In the following chapters the same grouping of the facts in a systematic process of evolution will appear again and again until the cumulative proof becomes irresistible.

CHAPTER VII.

FROM KANAB TO THE KAIBAB.

Distant view of the Kaibab.—The Kanab gap and the Permian.—Head of Kanab Cañon.—Sunset on the Kanab desert.—Hot days and cool nights.—Distant view of the terrace cliffs from the Kanab platform.—Reading geology thirty miles away.—Desert vegetation.—Approaching the plateau. Stewart's cañon.—Reaching water.—Sinking of the streams.—Entering the plateau.—Picturesque ravines.—Arboreal vegetation.—Forest vistas.—De Motte Park.—Arrangement of the drainage channels on the summit of the plateau.—Lagoons and subterranean drainage channels.—The Sylvan Gate and Little De Motte Park.—Milk Spring.—Reaching the brink.

The Kaibab is the loftiest of the four plateaus through which the Grand Cañon extends. It is from 1,500 to 2,000 feet higher than the Kanab Plateau on the west, and from 2,500 to 4,000 feet higher than the Marble Cañon platform on the east. Its superior altitude is due wholly to displacement and not to erosion, for the strata upon its summit are the same as those upon the surfaces of the others. The upheaval has produced a sharp fault upon the western flank and a great monoclinal flexure upon its eastern flank. Throughout its entire platform the upper Carboniferous forms the surface. The Kaibab begins at the base of the Vermilion Cliffs near the little village of Paria, its northern extremity terminating in a slender cusp. Steadily widening, and increasing very slowly in altitude, it reaches southward nearly a hundred miles to the Colorado River, where it attains a breadth of about 35 miles. Its highest point is about 9,280 feet above the sea, but most of its surface is between the altitudes of 7,800 and 9,000 feet.

When viewed from a distance its summit, projected against the sky, looks remarkably smooth and level. The slow increase of altitude from north to south may be discerned, and yet, in the absence of positive knowledge, it would be doubted by the careful observer whether this might not be due to perspective, and not real. When we actually visit the plateau we find the summit, seeming so smooth when viewed from afar, to be really

very rugged. It is scored with a minutely ramified system of ravines, varying much in depth, but averaging about 300 feet in the heart of the plateau, and much deeper at the flanks. The whole summit is magnificently forest-clad. In this respect it is in strong contrast to the other plateaus, excepting, however, in a much inferior way, the higher parts of the Uinkaret. The other plateaus are formidable deserts; the Kaibab is a paradise. The forests are due to the superior altitude of the plateau, for the higher the altitude the moister the climate. Through the southern portion of the Kaibab is cut the finest portion of the Grand Cañon. Vast and imposing as is the scenery at the foot of the Toroweap, the scenery of the Kaibab is much more impressive. I propose in the present chapter to describe, in familiar language, a journey from Kanab to the Kaibab, and to the brink of the chasm, where we may contemplate its sublimity.

Before us is the Permian terrace, rising by the gentlest of slopes; through it the Kanab River has cut a wide, shallow gap, in which stand several pretty little buttes carved sumptuously in the characteristic style of

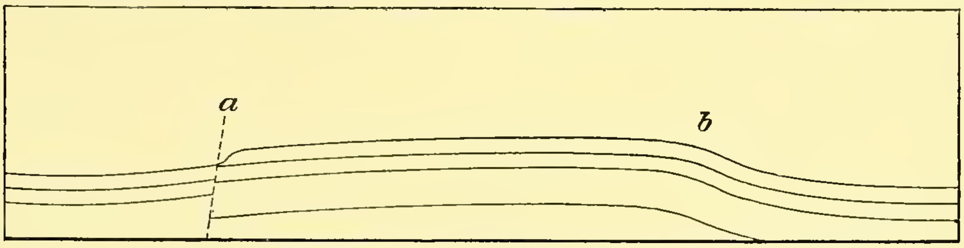


FIG. 3.—Section across the Kaibab. The vertical scale is double the horizontal. *a*, West Kaibab fault. *b*, East Kaibab monocline. Length of section about 32 miles.

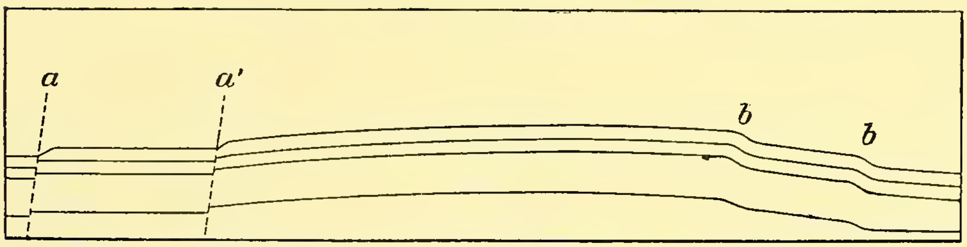


FIG. 4.—Section across the Kaibab. *a a'*, two branches of the West Kaibab fault. *b b'*, two branches of the East Kaibab monocline. The vertical scale is double the horizontal.

the formation. Beyond it the Carboniferous platform extends southward without visible bound. Over the Permian terrace the Kaibab is in full view, its flat unruffled summit occupying a whole quadrant of the horizon,

and its western escarpment facing towards us. The light of the declining sun* is upon it, and the larger details stand forth in clear relief, displaying the openings of grand ravines and the massive faces of the intervening pediments.

In the course of an hour we pass through the Permian gap, and the boundless desert is before us with the Kaibab upon our left. Our route is not directly towards the plateau front, but obliquely towards a point in it far to the southeast In the portion of the plateau nearest to us there is no water, either upon the summit or in the great ravines, and without water the journey would be indeed arduous. Moreover, it is the southern portion which commands our greatest interest, and the northern part possesses no features which are not still more advantageously presented in the southern. The southern prospect is very extended. The desert before us is really no more uneven than the rolling prairie of Iowa, but the range of vision is vastly greater. The reason is soon explained. In the prairie the curvature of the earth soon carries the surface out of sight. In the Kanab Desert we are constantly looking across a very wide but shallow depression of the surface, of which the center is located where Kanab Cañon begins to cut into the Carboniferous platform. In a word, the earth's surface is here slightly concave instead of convex, and the radius vector of the concavity has a length varying from 15 to 30 miles. Anywhere within the depression, therefore, the prospect is a very wide one. The general impression conveyed is that of a gently undulating plain of immense extent.

As the sun nears the horizon the desert scenery becomes exquisitely beautiful. The deep rich hues of the Permian, the intense red of the Vermilion Cliffs, the lustrous white of the distant Jurassic headlands are greatly heightened in tone and seem self-luminous. But more than all, the flood of purple and blue which is in the very air, bathing not only the naked rock faces, but even the obscurely tinted fronts of the Kaibab and the

* In midsummer it is best to begin this journey late in the afternoon. The distance between watering places is about 40 miles, and when the sun is high the heat upon the open desert is intense. The packs must be heavy, and if the attempt is made to accomplish the entire distance between sunrise and sunset, the animals are liable to be overtaxed, and what may be gained by a long march in a single day will be lost subsequently. It is better to start late in the afternoon, march until near midnight, and complete the distance to water the next morning. Night traveling is usually to be avoided, but here it is the better choice of two evils.

SUNSET ON THE KANAB DESERT.

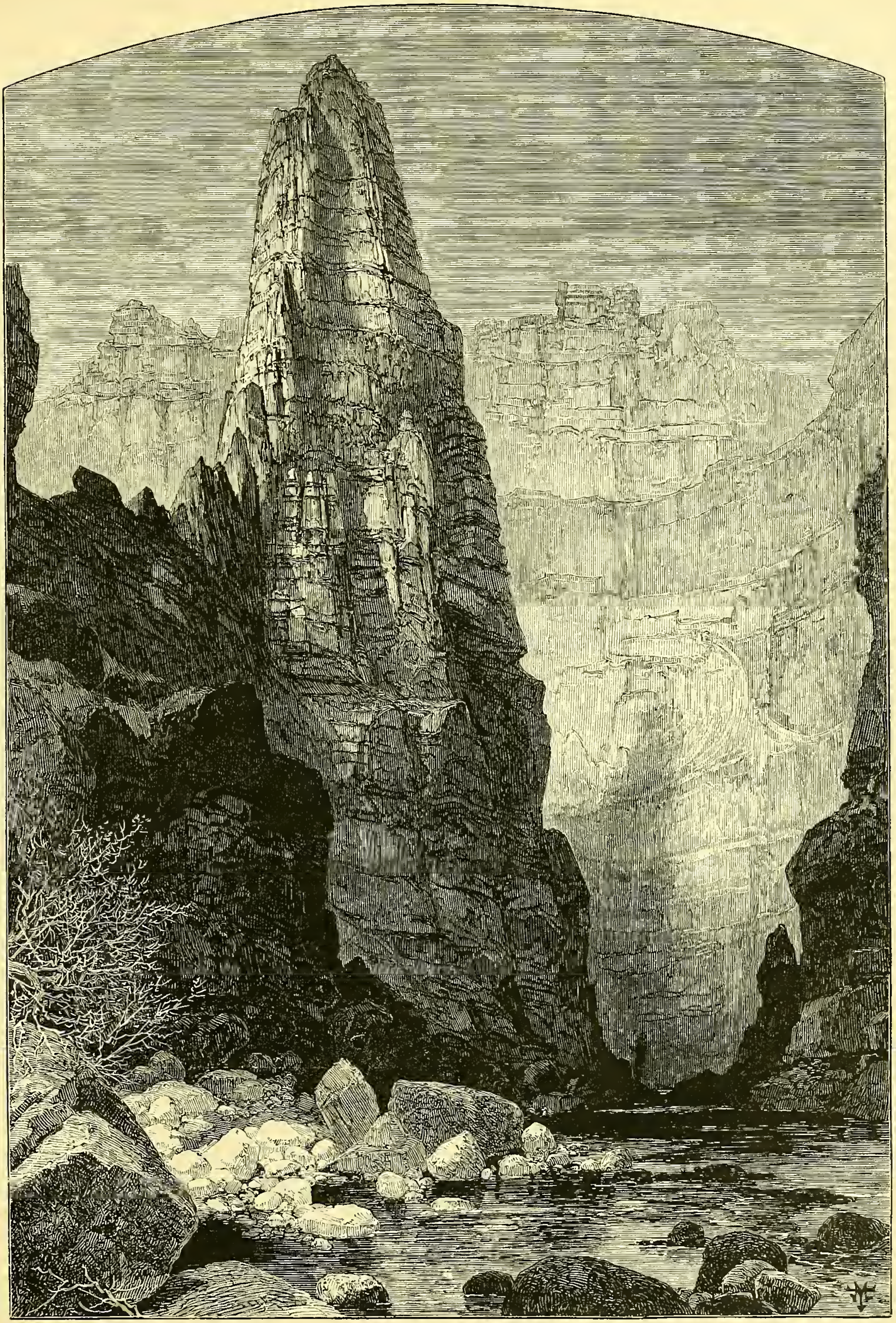
pale brown of the desert surface, clothes the landscape with its greatest charm. It is seen in its climax only in the dying hour of daylight. At length the sun disappears and the glory is extinguished.

Almost instantly the air becomes cool and refreshing, and as we ride onward through the deepening twilight it grows even chilly. It matters little how hot the days may be, the nights here are always cool and also dry. I have known the temperature of the air to be 110° at midday, falling to 54° at midnight, without any general atmospheric disturbance or change except that which is due to nocturnal radiation. Upon the open desert the air is almost always still both by day and night. Rarely do the high winds blow over it in summer, and even strong breezes are uncommon except in the vicinity of great cliffs. At night the stillness is profound, and unless there is water or green vegetation hard by, even the chirping of insects is unheard. The only sound which breaks upon the ear is the howling of the wolves that prowl about the camp and follow the tracks of the animals.

The hours roll quickly past as we move onward in the darkness. At length when the stars betoken the approach of midnight we halt, strip off the packs and saddles, hobble the animals and turn them loose to browse upon the scanty herbage. As the sun rises we are once more on the road. For ten miles from Kanab the trail descends by a hardly perceptible grade. Thence it ascends gradually at a rate of about 150 feet to the mile. From the fifteenth to the twenty-third mile it lies in shallow ravines, but at last emerges upon more open ground. As we look back towards the north, one of the grand spectacles of the Plateau country is disclosed to us. It is a view of the great cliffs which bound the southern terraces of the High Plateaus rising one above another. Nearly 10,000 feet of strata are exposed edgewise and occupy a line of frontage from 50 to 60 miles in length. It includes the stratigraphic series from the base of the Permian to the summit of the Lower Eocene. The view of the terraces from the north, from the brink of the Markágunt or Paunságunt, is of a very different character from this. There we see only their sloping summits with now and then a fragment of a mural front swung into view obliquely by the meandering course of the line of escarpment. Here the general line of frontage faces

us while the terrace platforms are invisible. The view is a distant one, but it requires great distance to bring into the field of vision an exposure so vast. At their nearest points the Permian is 15 miles away, the Trias 20, the Jura 35, and the Eocene more than 50. It should be observed that we are looking across the broad depression or concavity before spoken of, and that there is a gentle slope downwards for 15 miles to the base of the Permian, which lies 1,900 feet below us. Notwithstanding the distance there is no difficulty in distinguishing the different formations, and there would have been none even if we had never before seen the terraces, provided we had become familiar with their several aspects elsewhere; so strongly individualized are their colors and their sculptural forms. The Cretaceous alone is obscure, for in the portions of the terraces now in sight it does not form cliffs, but breaks down in long slopes covered with soil and débris. If we were a few miles farther west the Cretaceous cliffs of the Paria amphitheater would be visible and be as easily determined as the others; but here the Kaibab hides them. Although nearly 10,000 feet of strata are disclosed, the summit of the Eocene lies only 5,000 to 5,500 feet above the base of the Permian, for in the interval between the two exposures the northward dip of the whole mass has carried down the Eocene about 5,000 feet.

From every elevated point on the Kanab Plateau this magnificent display is in full view. All of the broader geological facts in the stratigraphy and structure of the terraces may be distinctly seen and interpreted. The increment in thickness of the Mesozoic strata towards the west is very plain. The effect of the great Sevier fault, which comes down from the High Plateaus, cutting across the terrace platforms and disappearing at the Pipe Spring promontory of the Vermilion Cliffs, is now visible. By a simple reconstruction, lifting up the thrown side of this fault and gradually depressing the westward extension of the strata until the Eocene is horizontal, we can restore mentally the whole mass to the attitude it held in Eocene time, and it will require but a slight effort of the imagination to detect the original configuration which determined the present positions of the drainage basins of the Virgen, Kanab, and Paria Rivers. With a measured base-line extending east and west upon this part of the Kanab Plateau, and with a fine large theodolite, it would be practicable to make all the measure-



KANAB CAÑON.—IN THE RED WALL LIMESTONE.

ments necessary for determining the masses and positions of the several stratigraphic members with a degree of accuracy not materially less than could be obtained by studying them upon their own ground.

A spectacle of this kind is most impressive to the geologist. It brings into one view the co-ordinated results of observations made laboriously by months of travel and inspection in a very broad and rugged field. The great distances through which the eye can reach, the aspect of cliffs towering above and beyond cliffs, the great cumulative altitude thus attained, the immensity of the masses revealed, the boldness of form, the distinctness of the lines of stratification, and especially the brilliant coloring, subdued indeed, but also refined by the haze, give to the scene a grandeur which has few parallels.

But we turn our backs upon it, and pursue our way, pausing anon to look at it with a reverent enthusiasm. The daylight discloses the western Kaibab wall upon our left, only five or six miles distant, and our course changes from southeast to south parallel to its front. Already we feel the influences of its long spurs sweeping outward and dying away in the desert platform, and the trail becomes more hilly. Once or twice it takes us down into ravines which are the continuations of the great chasms which cut it to its base and recede far into its mass, winding out of sight in profound depths. Vegetation has made its appearance all around us, not abundantly, indeed, but sufficiently to contrast with the desolation behind us. Upon the crest of the plateau we can see the giant pines and spruces, and we covet their luxurious shade. Nearer, on either hand, are piñons and cedars, mountain mahogany and mesquite, with many low forms of desert shrubbery. Many species of cactus are seen, the most abundant of which are the opuntias, or prickly pears. Of these there are four or five very common species. A large cactus "orchard" in blossom is a very beautiful sight, displaying flowers which, for beauty of form and richness of color, are seldom surpassed by the choicer gems of the conservatory. Nor is it less attractive when in the fruit, for it yields a multitude of purple "pears," which are very juicy and refreshing, and by no means contemptible in flavor. There is another form of cactus not likely to be forgotten by anybody who has once seen it, and which is very common on the Kanab desert. It is a stout

bush, with many branches, growing from 3 to 6 feet high. The trunk and branches have a hard, woody core, and are thickly fringed with rows of strong, sharp spines which present a very ferocious aspect Altogether it is the most truculent-looking member of the vegetable kingdom I happen to be acquainted with. Very common, too, are the yuccas, or "Spanish bayonets," which resemble, on a small scale, the noted agave or century plant. Another common species, somewhat resembling the last, bears a cluster of melon-like seed cases of the size and form of cucumbers, which the Indians gather and dry for food.*

At length the trail leads down into "Stewart's Cañon," a rather broad cañon valley descending towards us from the south. Just where we enter it it turns sharply to the west, forming an elbow, and, sinking thence ever deeper into the earth through a course of fifteen miles, it opens at last into the heart of Kanab Cañon at a depth of nearly 3,500 feet. Here at the elbow it is comparatively shallow. Before reaching the elbow it runs northward close to the base of the Kaibab wall, which rises more than 1,200 feet above its floor, while the opposite or western side is only about 400 feet high. The difference in the altitudes of the two sides is accounted for by the presence of the west Kaibab fault, which runs at the foot of the wall, throwing down the western side more than 800 feet. The geological relations here are worthy of some study. The presence of the fault is detected in a moment. Upon the western side the familiar grey limestones of the Upper Aubrey series form the entire wall. Upon the eastern side the same beds are seen upon the summit more than 800 feet higher than on the western side. Beneath them is the hard cross-bedded sandstone, and still lower down the brilliant red sandy shales of the lower Aubrey. Here, too, is seen that curious phenomenon so often presented in connection with the faults of this region. As the thrown beds approach the fault plane they are turned *down*.

The trail leads southward up Stewart's Cañon with an ascent that is barely perceptible. We become conscious of increasing altitude indirectly by the barometer and by the change in the vegetation. The desert shrubs

* The Mormons find a singular use for this plant. The pounded root, macerated in water, yields a thick liquid which makes a very good substitute for soap.

KANAB CAÑON.—NEAR THE JUNCTION.

have mostly disappeared and given place to the scrub-oaks and weeds which are the unfailing indications of a cooler and moister climate. But the most welcome sight is the close proximity of the yellow pines which stand upon the summit above and even upon the lower platform which looks down from the western side. As yet they do not grow in the valley bottom. We have not quite reached the Kaibab, though it is close at hand—nay, we pass right by its open gates which seem to invite us in with a welcome; for at intervals of a mile or two we perceive upon the left the openings of grand ravines leading up to its platform, and the moment we enter any one of them we are within the precincts of the great plateau. Stewart's Cañon is the trunk valley which receives the drainage of a considerable section of the western side of the Kaibab. The large affluents all come from the east, and none of any importance from the west.

About five miles from the point where the trail enters the valley we reach the first water—a tiny stream coming down from one of the great ravines and sinking into the soil a few hundred yards beyond the mouth. Halting long enough to allow the animals to drink, we move onward about two miles further up the valley and make camp. Here there comes out ot the Kaibab wall, about 300 feet above us, a stream of water as large as a man's body, which cascades down the rocks into a pool covering half an acre. There is a phenomenon here worth noticing, for it is a prelude to some very singular facts of general prevalence throughout this wonderful plateau. Across the outlet of the pool a rude dam has been constructed of stones and mud, which may be easily torn open or replaced. When the dam is open a large stream equal to the influx pours out of it, but the whole outpour sinks within a quarter of a mile. When the dam is closed the water in the pool rises about 15 inches, and there is no outflow. All the water which enters the pool then sinks along the newly submerged margin. A stream of that size anywhere else in the Plateau Country would ordinarily run eight or ten miles, and in a moist country would run much further. The sudden sinking of streams is by no means rare, but is generally exceptional. On the Kaibab it is the rule. Upon all its broad expanse there is nothing which can be properly called a brook or living stream. About a dozen springs are known, but their waters in every instance sink in the earth within a few hundred

yards of their sources. And the "Big Spring" in Stewart's Cañon yields several times as much water as all the others put together. With this foreknowledge the prospects of water supply upon the Kaibab might seem discouraging, but we shall not suffer for the want of it.

Although the sun is still high when the Big Spring is reached, nothing will be gained by prolonging the day's march, and it is well to take a look at the surroundings. In some way, without knowing exactly when and where, we seem to have gotten into the Kaibab; for around us is the sylvan scenery and a rolling country traversed by many valleys and ravines. True, they are not the finest types, but when we recall the desert we have just left, this place looks like a paradise. The barometer shows a considerable altitude, 7,850 feet, and the air though warm is not oppressive. As we approached the plateau from the desert and saw its battlements towering grandly in the distance and becoming hourly more grand, its level parapet retreating into indefinite distance in either direction, it never occurred to us that we might be spared the arduous struggle of scaling the wall, or, as a still more arduous alternative, the forcing of a rough passage through some narrow ravine for many miles. Yet we have reached this spot by a route as easy as an old-fashioned turnpike. In truth, the configuration of the southern part of the Kaibab could not be discerned as we approached it from the north But, putting together the observations of the journey, it now becomes apparent that the platform of the Kanab Plateau rises quite rapidly towards the south, while the Kaibab gains in altitude much more slowly. Opposite our last camp the difference in the altitudes of the two plateaus is about 2,300 feet. Here it has greatly diminished, and the passage from one to the other is now partly by a very gentle inclined plane and partly by a fault. Fifteen miles further south the fault vanishes or becomes insignificant, and the passage is by a long slope.*

Resuming in the morning the route up Stewart's Cañon, a half-hour's

*It may be remarked here that every fault in the district is accompanied with a corresponding break in the topography. A cliff or steep slope is produced by it. I do not recall an instance where the lifted beds are planed off by erosion, so as to make a continuous level with the thrown beds. The cliffs generated by displacement have a character of their own which the experienced observer distinguishes quickly and confidently from cliffs of erosion. These characteristic breaks in the topography often betray a fault in localities where it would otherwise have been passed over unnoticed and unsuspected.

ride brings us to an abandoned saw-mill. Here the trail leaves the valley which we have followed for ten miles and turns up into a large ravine coming from the east or southeast. It is much narrower than Stewart's Cañon, with very abrupt and almost precipitous walls about 600 feet high. The traveler in the Plateau Province learns to dread the necessity which compels him to thread a deep gorge or cañon unless he knows beforehand that there is a practicable and easy trail through it. If it is dry it is almost certain to be obstructed by fallen fragments and thickly set with scrub, its bottom scoured into rough gullies by the sudden floods; and half the time it will be necessary to mount the steep talus and thread it. If it carries a living stream the way is still worse, for, in addition to the foregoing difficulties, there are dangerous quicksands, impenetrable thickets of willows and thorny bushes, and the stream meanders from wall to wall. Unless there is a good trail the traveler will usually prefer to mount the cliff, if a break can be found in it, and seek the mesa above, and thus by a single struggle get rid of the miseries below. Not so the ravines of the Kaibab. Like the paths trodden by the pilgrims in the Delectable Mountains, "their ways are pleasantness and all their paths are peace." The ravine we enter is but a fair specimen of a vast number of them which cover the whole broad surface of the plateau with an infinite network of ramifications. Its bottom is covered with a carpet of grass and flowers growing rankly in a smooth firm soil free from rocks and undergrowth. Here and there a clump of aspens or noble pines grow in the way, but offer no obstacles to progress. It is like riding through a well-kept park or an avenue shaded by ancient trees. And now the effect of the absence of streams becomes manifest. Not only are there no perennial brooks, but there are no indications that even in the time of heavy rains or melting snow any notable amount of water ever runs in these channels. Yet the Kaibab is a moist region. In summer the rains are frequent and in winter the snow lies deep. Horses cannot winter there, and the wild cattle and deer, late in October, abandon it and seek the lower regions around its flanks. In all other plateaus or mountain ranges of equal mass and altitude and with equal precipitation there are many goodly streams, and even large creeks, fed throughout the summer by numberless copious springs; and when the snows melt these

streams become raging torrents. But so rare are the indications of running water on the Kaibab, even in times of melting snow or of vernal rains, that whenever we find a "wash" we look at it with surprise as if it were a strange phenomenon demanding special explanation. But the very absence of these traces of running water constitutes one of the greatest charms of the Kaibab, for every ravine is as smooth as a lawn and carpeted with a turf of mountain grass, richly decked with flowers of rare beauty and luxuriance.

The great trees grow chiefly upon the main platform above us. Except in the highest part of the plateau they are mostly the yellow pine (*Pinus ponderosa*), but large spruces are also common (*Abies grandis*, *A. Engelmanni*). Upon the flanks of the ravines they also grow, the pines upon the northern or sunny side, the spruces upon the opposite. In the valley bottom they grow scatteringly, and for the most part leave it quite open. Contrasting finely with these are the aspens (*Populus tremuloides*), with their white trunks and pale green foliage. Throughout the greater part of the plateau these three genera comprise all the arboreal forms that occur. But upon its borders we also find cedars, mountain mahogany, and piñon (*Juniperus occidentalis*, *Cercocarpus ledifolius*, and *Pinus edulis*), the latter, though classed as a pine, differing greatly from the more typical forms of the genus.

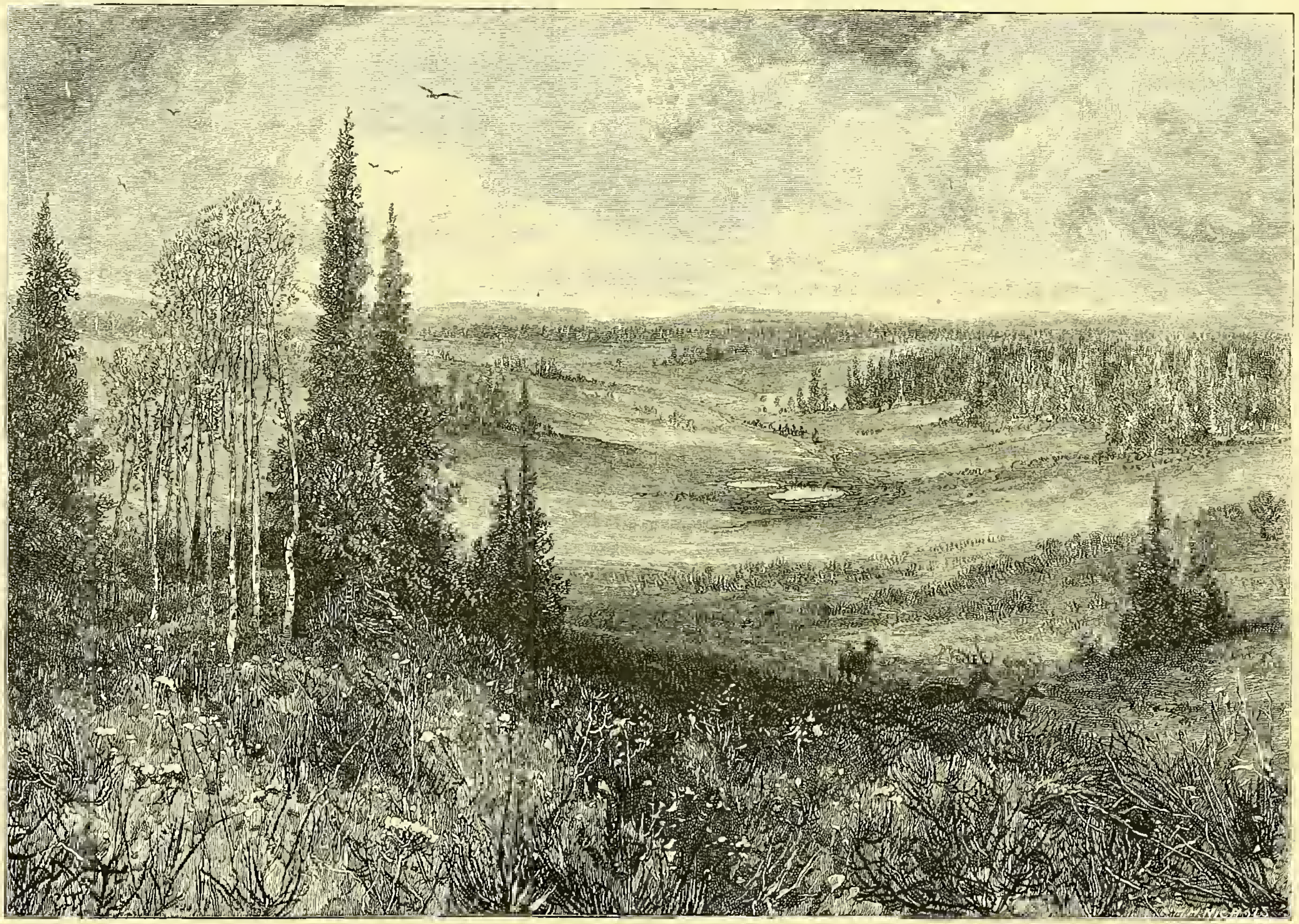
The ravine, where we enter its mouth, is about 600 feet in depth. The ascent is by a very easy grade, averaging about 100 feet to the mile. As we progress it becomes shallower, but not so rapidly as the grade might indicate, for the plateau summit also rises, though at a lower grade, towards the east. The course is a crooked one, but none the less agreeable on that account. Every traveler on foot or horseback has probably observed how tiresome and monotonous the road becomes when he can see it stretching away before him for many miles, and how charming the diversity when it wanders hither and thither. It matters not if the successive vistas are as much alike as two turns of a kaleidoscope, there is always an impatience to see what is beyond the next turn. So it is here. The successive scenes are much alike, or change by insensible degrees, but the same general view is presented in ever-varying detail, and its subject-matter is always delightful.

It is difficult to say precisely wherein the charm of the sylvan scenery of the Kaibab consists. We, who through successive summers have wandered through its forests and parks, have come to regard it as the most enchanting region it has ever been our privilege to visit. Surely there is no lack of beautiful or grand forest scenery in America, and it is a matter of taste what species of trees are the most pleasing. Probably few people would select the conifers and poplars as the highest types of arboreal beauty. I suspect that the charm consists in influences far more subtle than these outward forms. The delicious climate, neither cold nor hot, neither wet nor excessively dry, but always exhilarating, is a fundamental condition by virtue of which the body and mind are brought into the most susceptible mood. The ease with which we move from place to place, the absence of all anxiety or care for the three great requisites of camp life—fuel, water, and grass—are accessory conditions. The contrast of the desert, with its fatigue, its numberless discomforts and privations, is still another. But the scenery is also very beautiful in itself. The trees are large and noble in aspect and stand widely apart, except in the highest parts of the plateau, where the spruces predominate. Instead of dense thickets, where we are shut in by impenetrable foliage, we can look far beyond and see the tree trunks vanishing away like an infinite colonnade. The ground is unobstructed and inviting. There is a constant succession of parks and glades—dreamy avenues of grass and flowers winding between sylvan walls, or spreading out in broad open meadows. From June until September there is a display of wild flowers which is quite beyond description. The valley sides and platforms above are resplendent with dense masses of scarlet, white, purple, and yellow. It is noteworthy that, while the trees exhibit but few species, the humbler plants present a very great number, both of species and genera. In the upper regions of the High Plateaus, Mr. Lester F. Ward collected in a single season more than 600 species of plants, and the Kaibab, though offering a much smaller range of altitude and climate, would doubtless yield as rich a flora in proportion to the diversity of its conditions.

At a distance of about eight miles from its mouth, the ravine we have chosen has become very shallow, with gently sloping sides. At length we

leave it and ascend its right bank to the upper platform. The way here is as pleasant as before, for it is beneath the pines standing at intervals, varying from 50 to 100 feet, and upon a soil that is smooth, firm, and free from undergrowth. All is open, and we may look far into the depths of the forest on either hand. We now perceive that the surface of the plateau undulates with rolling hills and gently depressed vales. These valleys are the ramifications of the drainage channels. They are innumerable and cover the entire surface of the plateau. The main channels all deepen as they approach the edges of the plateau and often attain considerable depth, becoming at the same time precipitous. The deepest are those which emerge near the elbow of Stewart's Cañon and north of that point. These attain depths exceeding a thousand feet. The ravines which descend towards the eastern flank of the plateau terminate in a different manner, which we shall see hereafter. In the interior parts of the plateau these drainage valleys are all shallow, rarely exceeding 300 or 400 feet in depth, and seldom abrupt.

After two or three miles upon the summit, the trail descends into another valley, whose course we follow upward for about seven miles. At the distance of about twenty miles from Stewart's Cañon, we find that we have gained about 1,400 feet of altitude, and that the vegetation has changed its aspect somewhat. The pines, though still abundant, are now in the minority, and the spruces and aspens greatly predominate. The spruces form dense thickets on either hand, which nothing but the direst necessity would ever induce us to enter. Of this genus there are several species, varying much in habit. The great firs (*Abies grandis*, *A. Engelmanni*) are exceedingly beautiful on account of their sumptuous foliage. But the most common species is a smaller one (*A. subalpina*), with a tall and straight trunk, its branches spreading only five or six feet. These trees cluster so thickly together that a passage through them is extremely difficult and sometimes impossible. But we are not constrained to attempt it, for they seldom grow in the valley bottoms. Again we leave the ravine, and winding about among the hills, passing from glade to glade, we at length find ourselves upon the summit of a long slope, which descends rapidly into a great park, the largest on the Kaibab. It has received the name of



DEMOTTE PARK.

DE MOTTE PARK.

Its length is about ten miles, its average width about two miles. It is a depressed area in the heart of the plateau and is on every side girt about by more elevated ground rising by strong slopes 300 or 400 feet above its floor. The borders and heights above are densely forest-clad, but not a tree stands within the park itself. Descending into its basin and proceeding southward about two and a half miles, we reach a little spring where we make camp. The distance from the Big Spring to Stewart's Cañon is about 26 miles by trail.

De Motte Park is eminently adapted to be the "base of operations" in a campaign of geological investigation upon the southern part of the Kaibab. It is a central locality from which we may radiate in any direction to the bounds of the plateau. Here the great bulk of the supplies may be deposited, and from the supply camp we make journeys with light packs for one, two, or three days, as it may suit the convenience, and to it we may return to fit out for another short trip. The circumstances which make the park so advantageous in this respect are worth reciting.

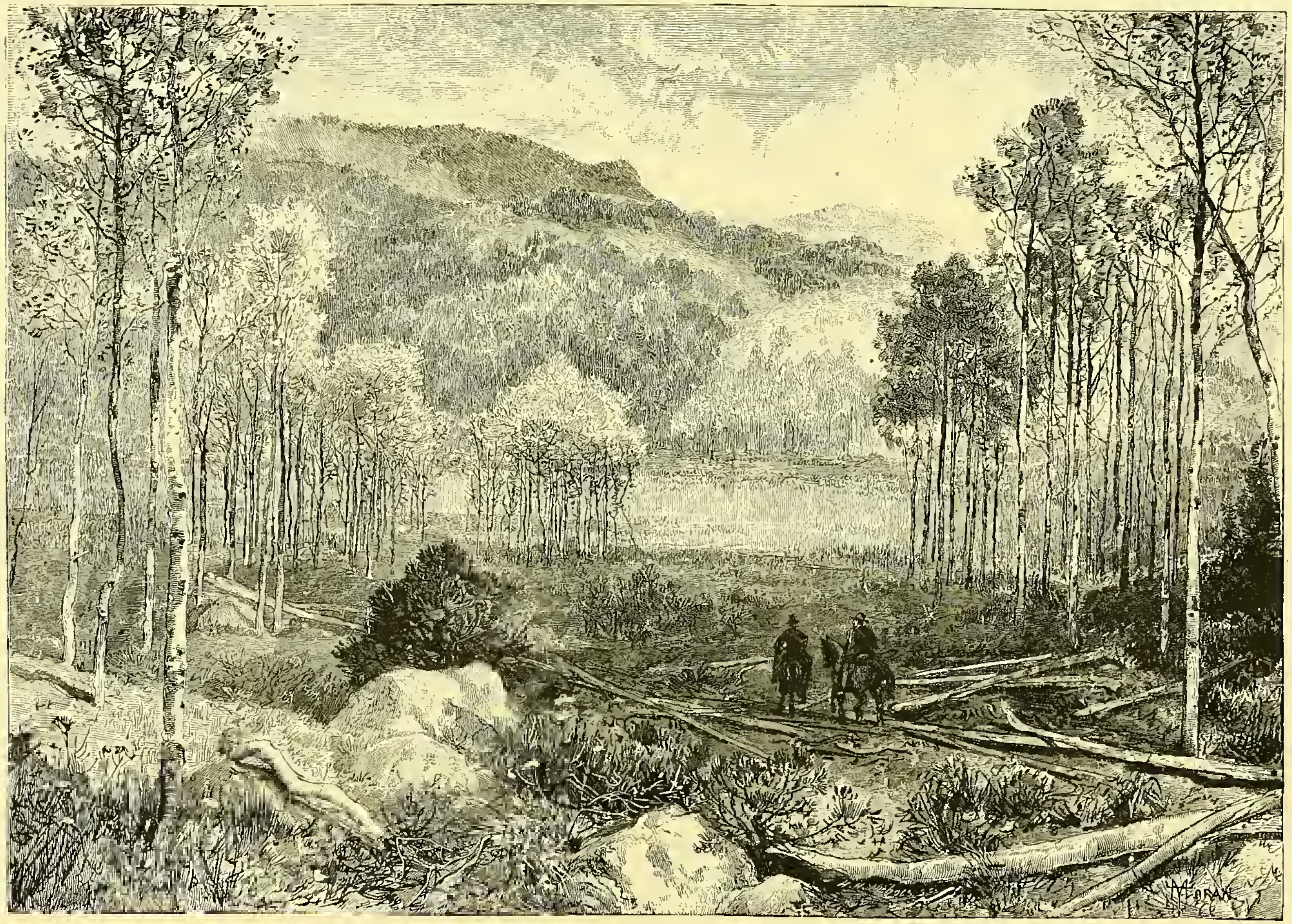
Notwithstanding the open character of the forest there are two difficulties in the way of travel on the Kaibab. The first has already been mentioned, scarcity of water. We know of about a dozen small springs, some of them conveniently located for the purposes of the explorer, others not. There is, however, another source of water supply which will be described presently. The second difficulty is the danger of getting lost and bewildered in the forest. This may seem to be a singular source of danger for an explorer, who of all men is bound to know his exact whereabouts at every step. But if he were to visit the Kaibab with that easy confidence and without a guide he would probably learn a severe lesson in less than a fortnight. The young Mormon herders who range over this region, and who follow a trail with the keen instincts of Indians, and with more than an Indian's intelligence, dread the mazes of the forest until they come to know them. Even the Indians who live and hunt there during the summer and autumn have sad tales about comrades lost when the snows came early and buried the trails so that they could not be followed. The bewildering

character arises from the monotony of the scenery. There are hundreds of hills and gulches, but they all look alike. There are no landmarks except trees, which are worse than none at all. If you enter a ravine for the second time at a point other than that at which you first entered it you would probably fail to recognize it. As with the faces of the Chinese, no conscientious white man would be willing to swear that he had ever seen any particular one before. Yet the riddle of the Kaibab is soon solved, and, once read, all danger is over. If the traveler is lost there is an infallible clew. He must go at once to De Motte Park. But how shall he find the way? If he has reason to suppose that he is within a dozen miles of it he has only to enter a main ravine and follow it to its head. This, however, does not apply to the portions of the plateau which lie more than five miles north of the park. The way may be long, but is easy and sure. A few ravines fade out before reaching the near neighborhood of the park. In that event take the nearest one on the right or left. All of them head upon the summit which looks down into the park. It is necessary, however, to keep to the *main* ravine and avoid its minor tributaries, and there is a criterion by which it may be distinguished At the confluence of a lateral ravine the grade of the main ravine is always the less of the two.

Although this may seem to be nothing more than a trivial bit of woodcraft, it really illustrates an important fact—the drainage system of a large portion of the Kaibab. The study of this drainage system will shed some light upon the geological history not only of the plateau itself, but of the region adjoining, and of the Grand Cañon.

The thought which must be predominant in the mind of one who for the first time enters the Kaibab is of the Grand Cañon. The fame of its grandeur is world-wide, and the desire to see it as it is grows stronger the nearer he approaches to it. This longing must be at least tempered, if not wholly satisfied, before the mind is in the humor to contemplate anything else. Our first expedition, then, shall be to the brink of the great abyss.

As the sun is rising and before his beams have penetrated to the bottom of the park we are on the way. On either hand is the forest, covering the slopes and the heights above, but ending suddenly at the foot of every incline. Before us to the southward stretches the open field with hardly an



LAGOON ON THE KAIBAB.

undulation. Six or seven miles away we can see the sylvan walls approach each other, leaving a narrow gateway between the tall spruces where the surface of the ground for a moment is sharply projected against the sky. The scene is, on the whole, a very attractive one. There is a great wealth of vegetation, somber indeed, and monotonous, but the darkness of the tone is suggestive of depth and richness of color. The only alleviating contrast is between the smooth expanse of the park and the myriads of sharp spikes which terminate the tree tops. The spirit of the scene is a calm, serene, and gentle one, touched with a tinge of solemnity and melancholy.

About a mile from camp we came upon an object worthy of attention. It is a rather deep depression in the earth about 200 feet across and very nearly circular. Within it is a large pool of water. Its depth below the valley floor may be about 40 feet, and the depth of the water 5 or 6 feet in the middle. It is a fair specimen of a frequent occurrence upon the Kaibab. I have never seen them elsewhere, and the explanation is difficult. The interest lies in the mystery of their origin. In every day's ride we usually find three or four of them and sometimes more. Some of them contain water, but the majority do not. Some hold water throughout the year, some only in the early summer or until autumn. They vary in size and depth very considerably. Some are as narrow as 20 feet; some are 300 to 400 feet across. The depths vary from a yard or two to a hundred feet. The form is crater-like—always approximately circular. They do not appear to occur under any special set of conditions. They are found as often upon the platforms as in the valleys, and are not uncommon upon the slopes of the ravines. In a few instances traces may be seen of rain gullies or washes leading into them, but not often, and none have ever been noted leading out of them. Whatever running water may enter them sinks within their basins; but it is certain that many of them rarely receive any running water. In the cases of those which do the wonder is that they do not soon fill up with sand and silt, for the water generated by heavy rain-storms or by melting snows, when sufficient in volume to run in a stream, is always thick with mud. The scarcity of running water on the Kaibab has been mentioned. Yet the precipitation is comparatively great and the evaporation small. It is apparent that all the water which falls upon its vast

expanse, with the exception of a slight percentage evaporated, must sink into the earth, where it is doubtless gathered in subterranean drainage channels, which open in the profound depths of the great amphitheaters of the Grand Cañon. In those depths are large creeks of perennial water issuing from the openings of those underground passages. This implies a system of subterranean rivulets, but it is not more wonderful than the endless caverns in the limestones of Kentucky and Indiana, and it is probably not upon so large a scale nor so greatly ramified. It also argues a high degree of permeability both in the upper strata and in the overmantling soil. The water sifts through them as easily as through sand, and rarely gathers into streams even in the most copious showers or most rapid melting of the snow. Whether these "lagoons" and "sink-holes," as we termed them, are the openings of pipes leading down into the subterranean rivers, and kept open by a gradual solution of the limestone, it is difficult to say. There are some difficulties in the way of this theory.

Moving rapidly southward, at length we reach the Sylvan Gate at the lower end. Passing through we immediately find ourselves at the head of a second park very similar to De Motte's, but smaller, having a length of nearly three miles. It is named Little De Motte Park, and the Sylvan Gate occupies a divide between the two. It contains a large lagoon holding stagnant water. There is a chain of these parks reaching from the northern end of De Motte's southward, a distance of 25 miles, separated only by necks of forest.

Our first objective point is a spring situated in one of the large ravines which head in the heights overlooking these two parks. Without some foreknowledge of the way to reach it, or without a guide, it would be impossible to find it, and the same is true of any other spring on the summit, but with this foreknowledge we seek the southwestern border of Little De Motte and enter the timber. During half an hour there is a miserable struggle with fallen trees and thick-set branches of spruce and aspen, but at length the heights are gained, and we descend into a shallow ravine, where the way is once more open. The winding glade, with smooth bottom richly carpeted with long green grass, aglow with myriads of beautiful blossoms, is before us, and the tall trees are on either hand. Soon it leads

into a larger one, and this into another, until at last the main ravine is reached. Very sweet and touching now are the influences of nature. The balmy air, the dark and somber spruces, the pale-green aspens, the golden shafts of sunlight shot through their foliage, the velvet sward—surely this is the home of the woodland nymphs, and at every turn of the way we can fancy we are about to see them flying at our approach or peeping at us from the flowery banks.

By half-past ten the spring is reached. Next to the Big Spring in Stewart's Cañon, it is the largest on the summit of the plateau. Here, too, is the only semblance of running water, for the stream flows a little more than half a mile before it sinks. The water is cold and delicious. It has a faint whitish cast, like that which would be produced by putting a drop or two of milk into a bucket of pure water. I presume it is caused by a fine precipitate of lime. We called it the "Milk Spring." Pausing here for a hasty lunch, and to fill the kegs (for to-night we may make a "dry" camp), we push on. We climb out of the ravine, and in fact we only came here to obtain water, as it is the only place near to the point of destination at which water can be procured. The route now becomes more rugged, leading across ravines and over intervening ridges, crossing the grain of the country, so to speak. But it is not difficult, for the pines have taken place of the spruces, and where the pines predominate the forest is very open. For eight miles from the Milk Spring we continue to cross hills and valleys, then follow a low swale shaded by giant pines with trunks three to four feet in thickness. The banks are a parterre of flowers. On yonder hillside, beneath one of these kingly trees, is a spot which seems to glow with an unwonted wealth of floral beauty. It is scarcely a hundred yards distant; let us pluck a bouquet from it. We ride up the slope.

The earth suddenly sinks at our feet to illimitable depths. In an instant, in the twinkling of an eye, the awful scene is before us.

CHAPTER VIII.

THE PANORAMA FROM POINT SUBLIME.

Abrupt disclosure of the spectacle.—Point Sublime.—The Grand Cañon an innovation in modern ideas. Familiarity required for a just appreciation.—Erroueous nature of precouceived notions.—Width of the chasm.—Extent of the panorama.—Vastness of its component objects.—Their multitude.—The infinity of details.—The grandeur and splendor of the buttes.—Lateral amphitheaters or side gorges.—Architectural styles of decoration.—The Cloisters.—Shiva's Temple.—Profusion of grand objects.—Color effects.—Atmospheric effects.—Sensitiveness of the picture to variations of light and shadow.—Effects of shadows and optical delusious.—The western haze.—Modulations of the picture through the day.—Sunset in the chasm.—The climax of the day.—Twilight.

Wherever we reach the Grand Cañon in the Kaibab it bursts upon the vision in a moment. Seldom is any warning given that we are near the brink. At the Toroweap it is quite otherwise. There we are notified that we are near it a day before we reach it. As the final march to that portion of the chasm is made the scene gradually develops, growing by insensible degrees more grand until at last we stand upon the brink of the inner gorge, where all is before us. In the Kaibab the forest reaches to the sharp edge of the cliff and the pine trees shed their cones into the fathomless depths below.

If the approach is made at random, with no idea of reaching any particular point by a known route, the probabilities are that it is first seen from the rim of one of the vast amphitheaters which set back from the main chasm far into the mass of the plateau. It is such a point to which the reader has been brought in the preceding chapter. Of course there are degrees in the magnitude and power of the pictures presented, but the smallest and least powerful is tremendous and too great for comprehension. The scenery of the amphitheaters far surpasses in grandeur and nobility anything else of the kind in any other region, but it is mere by-play in comparison with the panorama displayed in the heart of the cañon. The supreme views are to be obtained at the extremities of the long promontories, which jut out between

these recesses far into the gulf. Towards such a point we now direct our steps. The one we have chosen is on the whole the most commanding in the Kaibab front, though there are several others which might be regarded as very nearly equal to it, or as even more imposing in some respects. We named it *Point Sublime.*

The route is of the same character as that we have already traversed—open pine forest, with smooth and gently-rolling ground. The distance from the point where we first touched the rim of the amphitheater is about 5 miles. Nothing is seen of the chasm until about a mile from the end we come once more upon the brink. Reaching the extreme verge the packs are cast off, and sitting upon the edge we contemplate the most sublime and awe-inspiring spectacle in the world.

The Grand Cañon of the Colorado is a great innovation in modern ideas of scenery, and in our conceptions of the grandeur, beauty, and power of nature. As with all great innovations it is not to be comprehended in a day or a week, nor even in a month. It must be dwelt upon and studied, and the study must comprise the slow acquisition of the meaning and spirit of that marvelous scenery which characterizes the Plateau Country, and of which the great chasm is the superlative manifestation. The study and slow mastery of the influences of that class of scenery and its full appreciation is a special culture, requiring time, patience, and long familiarity for its consummation. The lover of nature, whose perceptions have been trained in the Alps, in Italy, Germany, or New England, in the Appalachians or Cordilleras, in Scotland or Colorado, would enter this strange region with a shock, and dwell there for a time with a sense of oppression, and perhaps with horror. Whatsoever things he had learned to regard as beautiful and noble he would seldom or never see, and whatsoever he might see would appear to him as anything but beautiful and noble. Whatsoever might be bold and striking would at first seem only grotesque. The colors would be the very ones he had learned to shun as tawdry and bizarre. The tones and shades, modest and tender, subdued yet rich, in which his fancy had always taken special delight, would be the ones which are conspicuously absent. But time would bring a gradual change. Some day he would suddenly become conscious that outlines which at first seemed

harsh and trivial have grace and meaning; that forms which seemed grotesque are full of dignity; that magnitudes which had added enormity to coarseness have become replete with strength and even majesty; that colors which had been esteemed unrefined, immodest, and glaring, are as expressive, tender, changeful, and capacious of effects as any others. Great innovations, whether in art or literature, in science or in nature, seldom take the world by storm. They must be understood before they can be estimated, and must be cultivated before they can be understood.

It is so with the Grand Cañon. The observer who visits its commanding points with the expectation of experiencing forthwith a rapturous exaltation, an ecstasy arising from the realization of a degree of grandeur and sublimity never felt before, is doomed to disappointment. Supposing him to be but little familiar with plateau scenery, he will be simply bewildered. Must he, therefore, pronounce it a failure, an overpraised thing? Must he entertain a just resentment towards those who may have raised his expectations too high? The answer is that subjects which disclose their full power, meaning, and beauty as soon as they are presented to the mind have very little of those qualities to disclose. Moreover, a visitor to the chasm or to any other famous scene must necessarily come there (for so is the human mind constituted) with a picture of it created by his own imagination. He reaches the spot, the conjured picture vanishes in an instant, and the place of it must be filled anew. Surely no imagination can construct out of its own material any picture having the remotest resemblance to the Grand Cañon. In truth, the first step in attempting a description is to beg the reader to dismiss from his mind, so far as practicable, any preconceived notion of it.

Those who have long and carefully studied the Grand Cañon of the Colorado do not hesitate for a moment to pronounce it by far the most sublime of all earthly spectacles. If its sublimity consisted only in its dimensions, it could be sufficiently set forth in a single sentence. It is more than 200 miles long, from 5 to 12 miles wide, and from 5,000 to 6,000 feet deep. There are in the world valleys which are longer and a few which are deeper. There are valleys flanked by summits loftier than the palisades of the Kai-

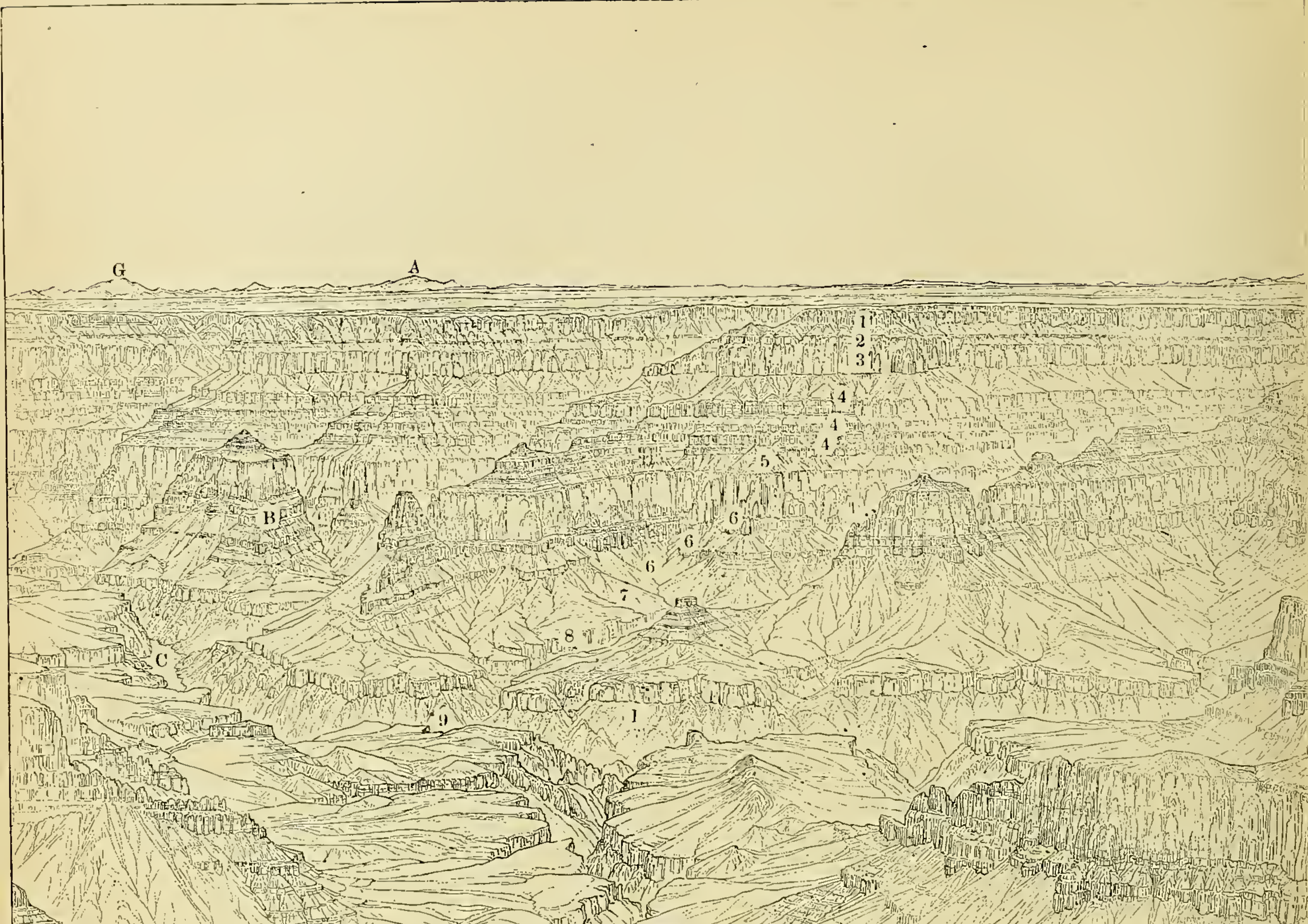
bab. Still the Grand Cañon is the sublimest thing on earth. It is so not alone by virtue of its magnitudes, but by virtue of the whole—its *ensemble.*

The common notion of a cañon is that of a deep, narrow gash in the earth, with nearly vertical walls, like a great and neatly cut trench. There are hundreds of chasms in the Plateau Country which answer very well to this notion. Many of them are sunk to frightful depths and are fifty to a hundred miles in length. Some are exceedingly narrow, as the cañons of the forks of the Virgen, where the overhanging walls shut out the sky. Some are intricately sculptured, and illuminated with brilliant colors; others are picturesque by reason of their bold and striking sculpture. A few of them are most solemn and impressive by reason of their profundity and the majesty of their walls. But, as a rule, the common cañons are neither grand nor even attractive. Upon first acquaintance they are curious and awaken interest as a new sensation, but they soon grow tiresome for want of diversity, and become at last mere bores. The impressions they produce are very transient, because of their great simplicity and the limited range of ideas they present. But there are some which are highly diversified, presenting many attractive features. These seldom grow stale or wearisome, and their presence is generally greeted with pleasure.

It is perhaps in some respects unfortunate that the stupendous pathway of the Colorado River through the Kaibabs was ever called a cañon, for the name identifies it with the baser conception. But the name presents as wide a range of signification as the word house. The log cabin of the rancher, the painted and vine-clad cottage of the mechanic, the home of the millionaire, the places where parliaments assemble, and the grandest temples of worship, are all houses. Yet the contrast between Saint Marc's and the rude dwelling of the frontiersman is not greater than that between the chasm of the Colorado and the trenches in the rocks which answer to the ordinary conception of a cañon. And as a great cathedral is an immense development of the rudimentary idea involved in the four walls and roof of a cabin, so is the chasm an expansion of the simple type of drainage channels peculiar to the Plateau Country. To the conception of its vast proportions must be added some notion of its intricate plan, the nobility of its architecture, its colossal buttes, its wealth of ornamentation, the splendor of

its colors, and its wonderful atmosphere. All of these attributes combine with infinite complexity to produce a whole which at first bewilders and at length overpowers.

From the end of Point Sublime, the distance across the chasm to the nearest point in the summit of the opposite wall is about 7 miles. This, however, does not fairly express the width of the chasm, for both walls are recessed by wide amphitheaters, setting far back into the platform of the country, and the promontories are comparatively narrow strips between them. A more correct statement of the general width would be from 11 to 12 miles. This must dispose at once of the idea that the chasm is a narrow gorge of immense depth and simple form. It is somewhat unfortunate that there is a prevalent idea that in some way an essential part of the grandeur of the Grand Cañon is the narrowness of its defiles. Much color has been given to this notion by the first illustrations of the cañon from the pencil of Egloffstein in the celebrated report of Lieutenant Ives. Never was a great subject more artistically misrepresented or more charmingly belittled. Nowhere in the Kaibab section is any such extreme narrowness observable, and even in the Uinkaret section the width of the great inner gorge is a little greater than the depth. In truth, a little reflection will show that such a character would be inconsistent with the highest and strongest effects. For it is obvious that some notable width is necessary to enable the eye to see the full extent of the walls. In a chasm one mile deep, and only a thousand feet wide, this would be quite impossible. If we compare the Marble Cañon or the gorge at the Toroweap with wider sections it will at once be seen that the wider ones are much stronger. If we compare one of the longer alcoves having a width of 3 or 4 miles with the view across the main chasm the advantage will be overwhelmingly with the latter. It is evident that for the display of wall surface of given dimensions a certain amount of distance is necessary. We may be too near or too far for the right appreciation of its magnitude and proportions. The distance must bear some ratio to the magnitude. But at what precise limit this distance must in the present case be fixed is not easy to determine. It can hardly be doubted that if the cañon were materially narrower it would suffer a loss of grandeur and effect.

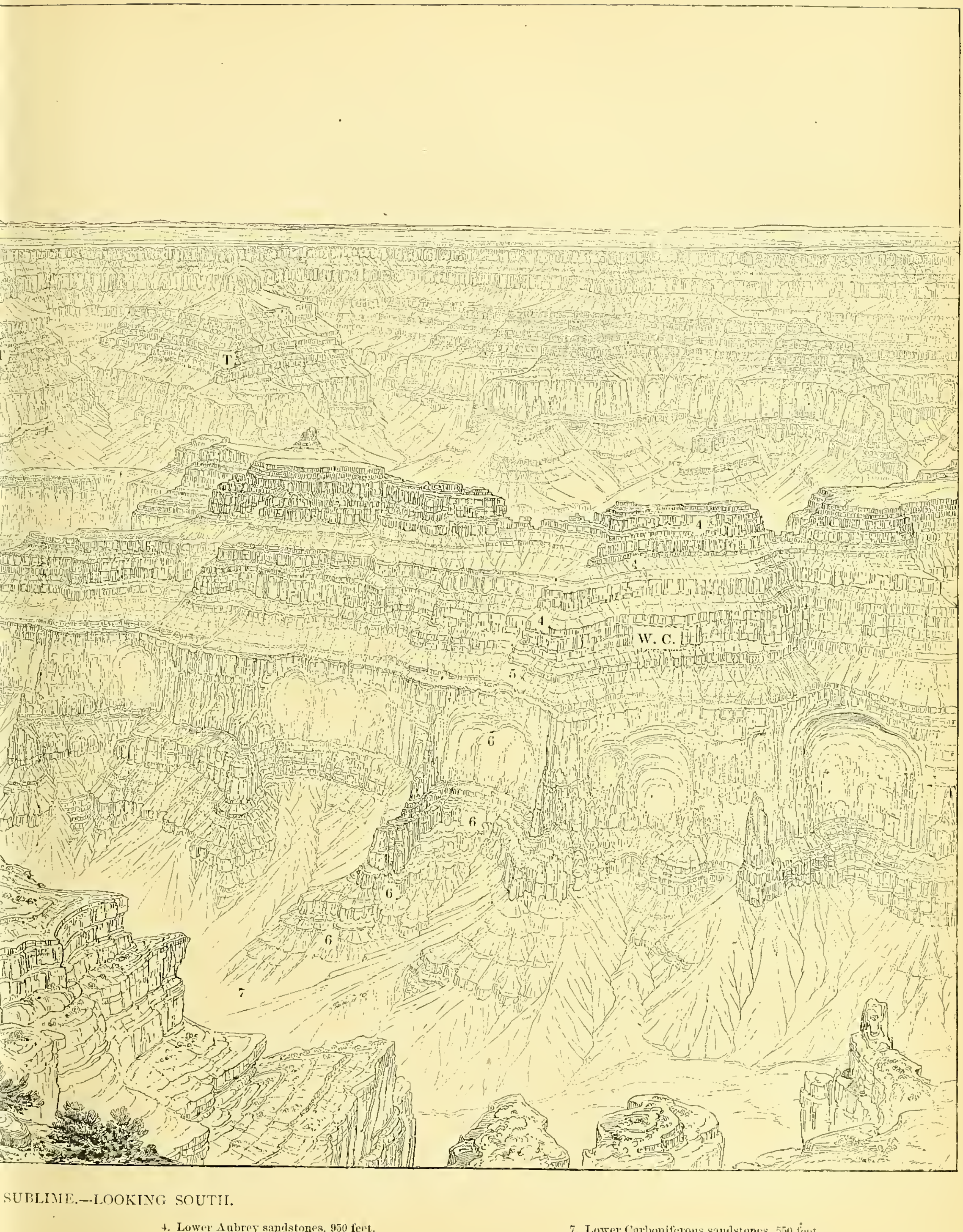


KEY TO THE PANORAMA FROM PO

A. Bill William's Peak.
B. Tower of Babel.
C. Colorado River.
F. Mount Floyd.

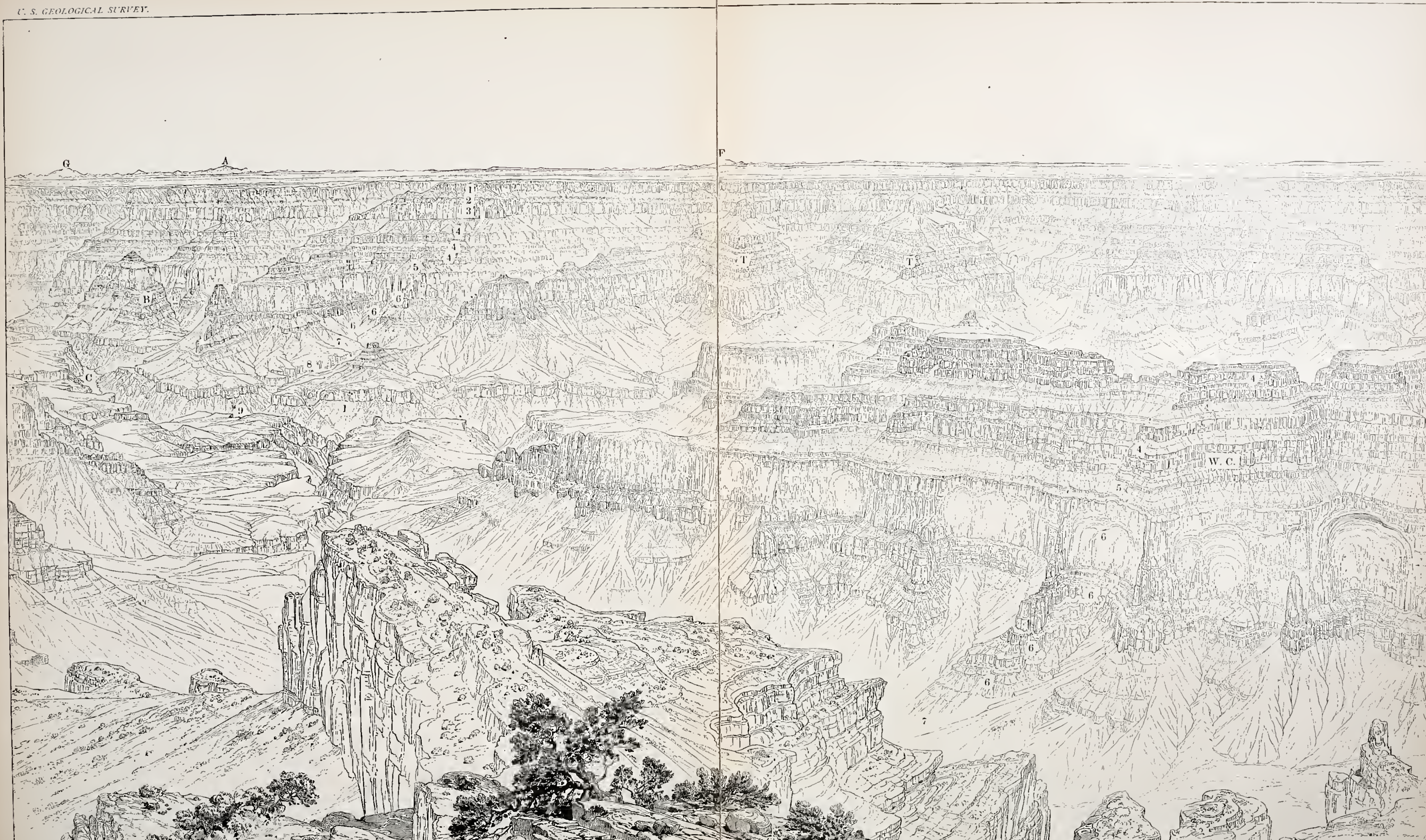
G. Mount Sitgreaves.
I. Inner Gorge.
T. T. Twin Temples.
W. C. West Cloister.

1. Cherty limestone, 240 feet.
2. Upper Aubrey limestone, 320 fe
3. Cross-bedded sandstone, 380 feet



SUBLIME.—LOOKING SOUTH.

4. Lower Aubrey sandstones, 950 feet.
5. Upper Red Wall sandstones, 400 feet.
6. Red Wall limestones, 1,500 feet.
7. Lower Carboniferous sandstones, 550 feet.
8. Quartzite base of Carboniferous, 180 feet.
9. Archaean.



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The length of cañon revealed clearly and in detail at Point Sublime is about 25 miles in each direction. Towards the northwest the vista terminates behind the projecting mass of Powell's Plateau. But again to the westward may be seen the crests of the upper walls reaching through the Kanab and Uinkaret Plateaus, and finally disappearing in the haze about 75 miles away.

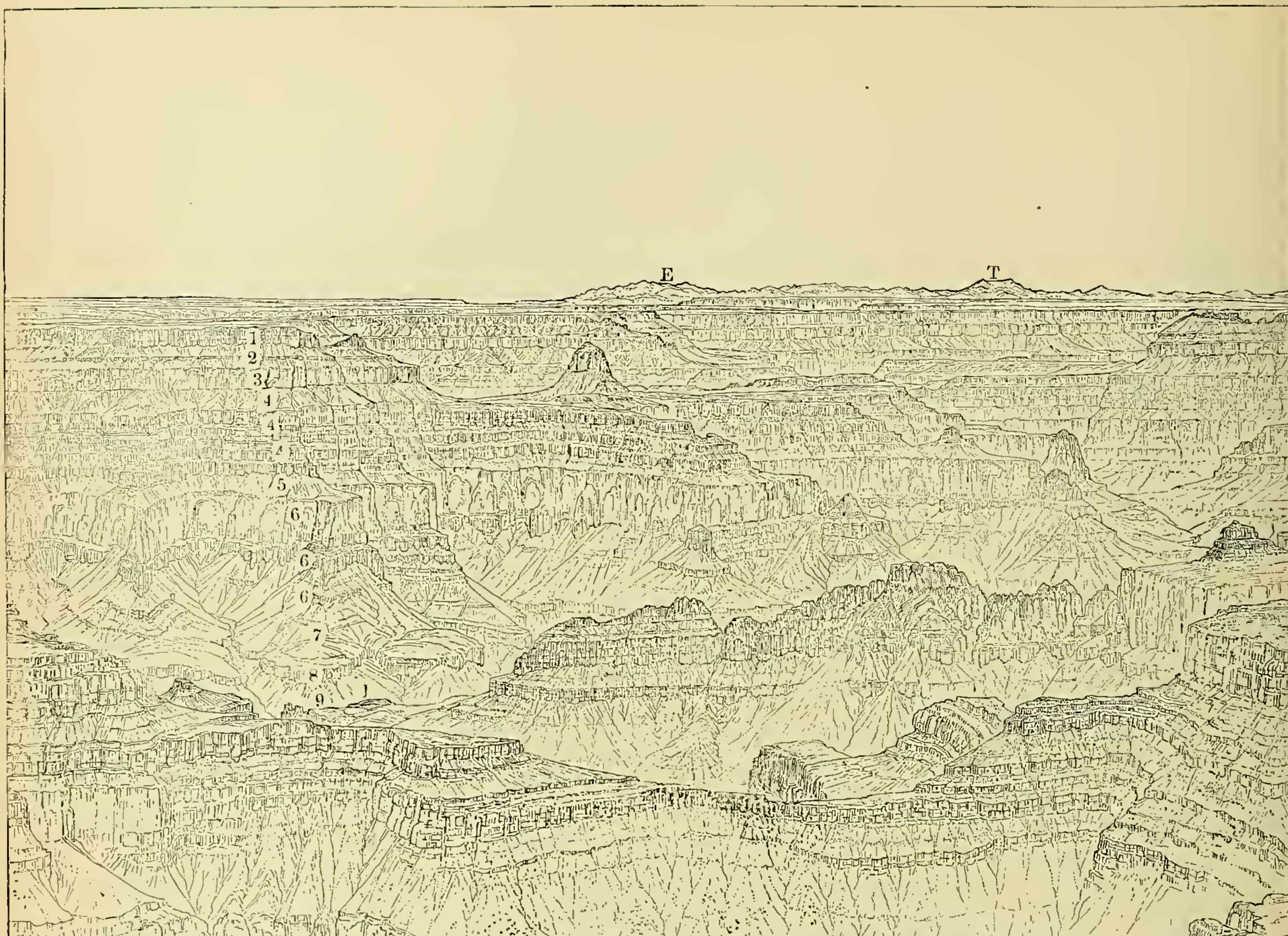
The space under immediate view from our standpoint, 50 miles long and 10 to 12 wide, is thronged with a great multitude of objects so vast in size, so bold yet majestic in form, so infinite in their details, that as the truth gradually reveals itself to the perceptions it arouses the strongest emotions. Unquestionably the great, the overruling feature is the wall on the opposite side of the gulf. Can mortal fancy create a picture of a mural front a mile in height, 7 to 10 miles distant, and receding into space indefinitely in either direction? As the mind strives to realize its proportions its spirit is broken and its imagination completely crushed. If the wall were simple in its character, if it were only blank and sheer, some rest might be found in contemplating it; but it is full of diversity and eloquent with grand suggestions. It is deeply recessed by alcoves and amphitheaters receding far into the plateau beyond, and usually disclosing only the portals by which they open into the main chasm. Between them the promontories jut out, ending in magnificent gables with sharp mitered angles. Thus the wall rambles in and out, turning numberless corners. Many of the angles are acute, and descend as sharp spurs like the forward edge of a plowshare. Only those alcoves which are directly opposite to us can be seen in their full length and depth. Yet so excessive, nay so prodigious, is the effect of foreshortening, that it is impossible to realize their full extensions. We have already noted this effect in the Vermilion Cliffs, but here it is much more exaggerated. At many points the profile of the façade is thrown into view by the change of trend, and its complex character is fully revealed. Like that of the Vermilion Cliffs, it is a series of many ledges and slopes, like a molded plinth, in which every stratum is disclosed as a line or a course of masonry. The Red Wall limestone is the most conspicuous member, presenting its vertical face eight hundred to a thousand feet high, and everywhere unbroken. The thinner beds more often appear in the slopes as a

succession of ledges projecting through the scanty talus which never conceals them.

Numerous detached masses are also seen flanking the ends of the long promontories. These buttes are of gigantic proportions, and yet so overwhelming is the effect of the wall against which they are projected that they seem insignificant in mass, and the observer is often deluded by them, failing to perceive that they are really detached from the wall and perhaps separated from it by an interval of a mile or two.

At the foot of this palisade is a platform through which meanders the inner gorge, in whose dark and somber depths flows the river. Only in one place can the water surface be seen. In its windings the abyss which holds it extends for a short distance towards us and the line of vision enters the gorge lengthwise. Above and below this short reach the gorge swings its course in other directions and reveals only a dark, narrow opening, while its nearer wall hides its depths. This inner chasm is 1,000 to 1,200 feet deep. Its upper 200 feet is a vertical ledge of sandstone of a dark rich brownish color. Beneath it lies the granite of a dark iron-gray shade, verging towards black, and lending a gloomy aspect to the lowest deeps. Perhaps a half mile of the river is disclosed. A pale, dirty red, without glimmer or sheen, a motionless surface, a small featureless spot, inclosed in the dark shade of the granite, is all of it that is here visible. Yet we know it is a large river, a hundred and fifty yards wide, with a headlong torrent foaming and plunging over rocky rapids.

A little, and only a little, less impressive than the great wall across the chasm are the buttes upon this side. And such buttes! All others in the west, saving only the peerless Temples of the Virgen, are mere trifles in comparison with those of the Grand Cañon. In nobility of form, beauty of decoration, and splendor of color, the Temples of the Virgen must, on the whole, be awarded the palm; but those of the Grand Cañon, while barely inferior to them in those respects, surpass them in magnitude and fully equal them in majesty. But while the Valley of the Virgen presents a few of these superlative creations, the Grand Cañon presents them by dozens. In this relation the comparison would be analogous to one between a fine cathedral town and a metropolis like London or Paris. In truth, there is only a very



KEY TO THE PANORAMA FR

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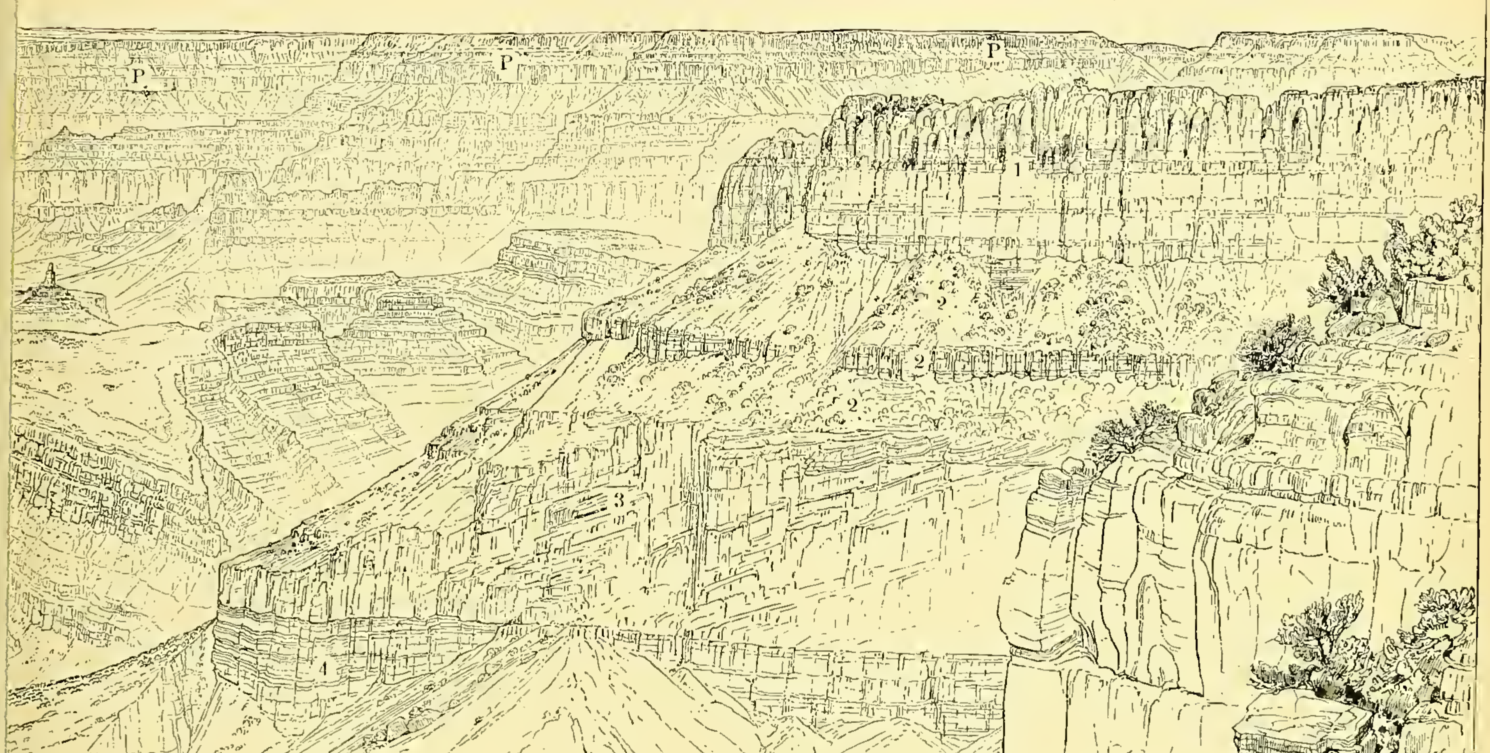
I. Inner Gorge.
P. Powell's Plateau.
T. Mount Trumbull.

1. Cherty limestone.
2. Upper Aubrey limestone.
3. Cross-bedded sandstone.



POINT SUBLIME.—LOOKING WEST.

4. Lower Aubrey sandstones.
5. Upper Red Wall sandstones.
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limited ground of comparison between the two localities, for in style and effects their respective structures differ as decidedly as the works of any two well-developed and strongly contrasted styles of human architecture.

Whatsoever is forcible, characteristic, and picturesque in the rock-forms of the Plateau Country is concentrated and intensified to the uttermost in the buttes. Wherever we find them, whether fringing the long escarpments of terraces or planted upon broad mesas, whether in cañons or upon expansive plains, they are always bold and striking in outline and ornate in architecture. Upon their flanks and entablatures the decoration peculiar to the formation out of which they have been carved is most strongly portrayed and the profiles are most sharply cut. They command the attention with special force and quicken the imagination with a singular power. The secret of their impressiveness is doubtless obscure. Why one form should be beautiful and another unattractive; why one should be powerful, animated, and suggestive, while another is meaningless, are questions for the metaphysician rather than the geologist. Sufficient here is the fact. Yet there are some elements of impressiveness which are too patent to escape recognition. In nearly all buttes there is a certain *definiteness* of form which is peculiarly emphatic, and this is seen in their profiles. Their ground-plans are almost always indefinite and capricious, but the profiles are rarely so. These are usually composed of lines which have an approximate and sometimes a sensibly perfect geometrical definition. They are usually few and simple in their ultimate analysis, though by combination they give rise to much variety. The ledges are vertical, the summits are horizontal, and the taluses are segments of hyperbolas of long curvature and concave upwards. These lines greatly preponderate in all cases, and though others sometimes intrude they seldom blemish greatly the effects produced by the normal ones. All this is in striking contrast with the ever-varying, indefinite profiles displayed in mountains and hills or on the slopes of valleys. The profiles generated by the combinations of these geometric lines persist along an indefinite extent of front. Such variations as occur arise not from changes in the nature of the lines, but in the modes of combination and proportions. These are never great in any front of moderate extent, but are just sufficient to relieve it

from a certain monotony which would otherwise prevail. The same type and general form is persistent. Like the key-note of a song, the mind carries it in its consciousness wherever the harmony wanders.

The horizontal lines or courses are equally strong. These are the edges of the strata, and the deeply eroded seams where the superposed beds touch each other. Here the uniformity as we pass from place to place is conspicuous. The Carboniferous strata are quite the same in every section, showing no perceptible variation in thickness through great distances, and only a slight dip.

It is readily apparent, therefore, that the effect of these profiles and horizontal courses so persistent in their character is highly architectural. The relation is more than a mere analogy or suggestion; it is a vivid resemblance. Its failure or discordance is only in the ground plan, though it is not uncommon to find a resemblance, even in this respect, among the Permian buttes. Among the buttes of the Grand Cañon there are few striking instances of definiteness in ground plan. The finest butte of the chasm is situated near the upper end of the Kaibab division; but it is not visible from Point Sublime. It is more than 5,000 feet high, and has a surprising resemblance to an Oriental pagoda. We named it Vishnu's Temple.

On either side of the promontory on which we stand is a side gorge sinking nearly 4,000 feet below us. The two unite in front of the point, and, ever deepening, their trunk opens into the lowest abyss in the granite at the river. Across either branch is a long rambling mass, one on the right of us, the other on the left. We named them the Cloisters. They are excellent types of a whole class of buttes which stand in close proximity to each other upon the north side of the chasm throughout the entire extent of the Kaibab division. A far better conception of their forms and features can be gained by an examination of Mr. Holmes's panoramic picture than by reading a whole volume of verbal description. The whole prospect, indeed, is filled with a great throng of similar objects, which, as much by their multitude as by their colossal size, confuse the senses; but these, on account of their proximity, may be most satisfactorily studied. The infinity of sharply defined detail is amazing. The eye is instantly caught and the attention firmly held by its systematic character. The parallelism of the

lines of bedding is most forcibly displayed in all the windings of the façades, and these lines are crossed by the vertical scorings of numberless waterways. Here, too, are distinctly seen those details which constitute the peculiar style of decoration prevailing throughout all the buttes and amphitheaters of the Kaibab. The course of the walls is never for a moment straight, but extends as a series of cusps and re-entrant curves. Elsewhere the reverse is more frequently seen; the projections of the wall are rounded and are convex towards the front, while the re-entrant portions are cusp-like recesses. This latter style of decoration is common in the Permian buttes and is not rare in the Jurassic. It produces the effect of a thickly set row of pilasters. In the Grand Cañon the reversal of this mode produces the effect of panels and niches. In the western Cloister may be seen a succession of these niches, and though they are mere details among myriads, they are really vast in dimensions. Those seen in the Red Wall limestone are over 600 feet high, and are overhung by arched lintels with spandrels.

As we contemplate these objects we find it quite impossible to realize their magnitude. Not only are we deceived, but we are conscious that we are deceived, and yet we cannot conquer the deception We cannot long study our surroundings without becoming aware of an enormous disparity in the effects produced upon the senses by objects which are immediate and equivalent ones which are more remote. The depth of the gulf which separates us from the Cloisters cannot be realized. We crane over the brink, and about 700 feet below is a talus, which ends at the summit of the cross-bedded sandstone. We may see the bottom of the gorge, which is about 3,800 feet beneath us, and yet the talus seems at least half-way down. Looking across the side gorge the cross-bedded sandstone is seen as a mere band at the summit of the Cloister, forming but a very small portion of its vertical extent, and, whatever the reason may conclude, it is useless to attempt to persuade the imagination that the two edges of the sandstone lie in the same horizontal plane. The eastern Cloister is nearer than the western, its distance being about a mile and a half. It seems incredible that it can be so much as one-third that distance. Its altitude is from 3,500 to 4,000 feet, but any attempt to estimate the altitude by means of visual impressions is felt at once to be hopeless. There is no stadium. Dimensions

mean nothing to the senses, and all that we are conscious of in this respect is a troubled sense of immensity.

Beyond the eastern Cloister, five or six miles distant, rises a gigantic mass which we named Shiva's Temple. It is the grandest of all the buttes, and the most majestic in aspect, though not the most ornate. Its mass is as great as the mountainous part of Mount Washington. That summit looks down 6,000 feet into the dark depths of the inner abyss, over a succession of ledges as impracticable as the face of Bunker Hill Monument. All around it are side gorges sunk to a depth nearly as profound as that of the main channel. It stands in the midst of a great throng of cloister-like buttes, with the same noble profiles and strong lineaments as those immediately before us, with a plexus of awful chasms between them. In such a stupendous scene of wreck it seemed as if the fabled "Destroyer" might find an abode not wholly uncongenial.

In all the vast space beneath and around us there is very little upon which the mind can linger restfully. It is completely filled with objects of gigantic size and amazing form, and as the mind wanders over them it is hopelessly bewildered and lost. It is useless to select special points of contemplation. The instant the attention lays hold of them it is drawn to something else, and if it seeks to recur to them it cannot find them. Everything is superlative, transcending the power of the intelligence to comprehend it. There is no central point or object around which the other elements are grouped and to which they are tributary. The grandest objects are merged in a congregation of others equally grand. Hundreds of these mighty structures, miles in length, and thousands of feet in height, rear their majestic heads out of the abyss, displaying their richly-molded plinths and friezes, thrusting out their gables, wing-walls, buttresses, and pilasters, and recessed with alcoves and panels. If any one of these stupendous creations had been planted upon the plains of central Europe it would have influenced modern art as profoundly as Fusiyama has influenced the decorative art of Japan. Yet here they are all swallowed up in the confusion of multitude It is not alone the magnitude of the individual objects that makes this spectacle so portentous, but it is still more the extravagant pro-

GRANITE FALLS.—KAIBAB DIVISION.—GRAND CAÑON.

fusion with which they are arrayed along the whole visible extent of the broad chasm.

The color effects are rich and wonderful. They are due to the inherent colors of the rocks, modified by the atmosphere. Like any other great series of strata in the Plateau Province, the Carboniferous has its own range of characteristic colors, which might serve to distinguish it even if we had no other criterion. The summit strata are pale grey, with a faint yellowish cast. Beneath them the cross-bedded sandstone appears, showing a mottled surface of pale pinkish hue. Underneath this member are nearly 1,000 feet of the lower Aubrey sandstones, displaying an intensely brilliant red, which is somewhat masked by the talus shot down from the grey, cherty limestones at the summit. Beneath the Lower Aubrey is the face of the Red Wall limestone, from 2,000 to 3,000 feet high. It has a strong red tone, but a very peculiar one. Most of the red strata of the west have the brownish or vermilion tones, but these are rather purplish-red, as if the pigment had been treated to a dash of blue. It is not quite certain that this may not arise in part from the intervention of the blue haze, and probably it is rendered more conspicuous by this cause; but, on the whole, the purplish cast seems to be inherent. This is the dominant color-mass of the cañon, for the expanse of rock surface displayed is more than half in the Red Wall group. It is less brilliant than the fiery red of the Aubrey sandstones, but is still quite strong and rich. Beneath are the deep browns of the lower Carboniferous. The dark iron-black of the hornblendic schists revealed in the lower gorge makes but little impression upon the boundless expanse of bright colors above.

The total effect of the entire color-mass is bright and glowing. There is nothing gloomy or dark in the picture, except the opening of the inner gorge, which is too small a feature to influence materially the prevailing tone. Although the colors are bright when contrasted with normal landscapes, they are decidedly less intense than the flaming hues of the Trias or the dense cloying colors of the Permian; nor have they the refinement of those revealed in the Eocene. The intense luster which gleams from the rocks of the Plateau Country is by no means lost here, but is merely subdued and kept under some restraint. It is toned down and softened without

being deprived of its character. Enough of it is left to produce color effects not far below those that are yielded by the Jura-Trias.

But though the inherent colors are less intense than some others, yet under the quickening influence of the atmosphere they produce effects to which all others are far inferior. And here language fails and description becomes impossible. Not only are their qualities exceedingly subtle, but they have little counterpart in common experience. If such are presented elsewhere they are presented so feebly and obscurely that only the most discriminating and closest observers of nature ever seize them, and they so imperfectly that their ideas of them are vague and but half real. There are no concrete notions founded in experience upon which a conception of these color effects and optical delusions can be constructed and made intelligible. A perpetual glamour envelops the landscape. Things are not what they seem, and the perceptions cannot tell us what they are. It is not probable that these effects are different in kind in the Grand Cañon from what they are in other portions of the Plateau Country. But the difference in degree is immense, and being greatly magnified and intensified many characteristics become palpable which elsewhere elude the closest observation.

In truth, the tone and temper of the landscape are constantly varying, and the changes in its aspect are very great. It is never the same, even from day to day, or even from hour to hour. In the early morning its mood and subjective influences are usually calmer and more full of repose than at other times, but as the sun rises higher the whole scene is so changed that we cannot recall our first impressions. Every passing cloud, every change in the position of the sun, recasts the whole. At sunset the pageant closes amid splendors that seem more than earthly. The direction of the full sunlight, the massing of the shadows, the manner in which the side lights are thrown in from the clouds determine these modulations, and the sensitiveness of the picture to the slightest variations in these conditions is very wonderful.

The shadows thrown by the bold abrupt forms are exceedingly dark. It is almost impossible at the distance of a very few miles to distinguish even broad details in these shadows. They are like remnants of midnight

unconquered by the blaze of noonday. The want of half tones and gradations in the light and shade, which has already been noted in the Vermilion Cliffs, is apparent here, and is far more conspicuous. Our thoughts in this connection may suggest to us a still more extreme case of a similar phenomenon presented by the half-illuminated moon when viewed through a large telescope. The portions which catch the sunlight shine with great luster, but the shadows of mountains and cliffs are black and impenetrable. But there is one feature in the cañon which is certainly extraordinary. It is the appearance of the atmosphere against the background of shadow. It has a metallic luster which must be seen to be appreciated. The great wall across the chasm presents at noonday, under a cloudless sky, a singularly weird and unearthly aspect. The color is for the most part gone. In place of it comes this metallic glare of the haze. The southern wall is never so poorly lighted as at noon. Since its face consists of a series of promontories projecting towards the north, these projections catch the sunlight on their eastern sides in the forenoon, and upon their western sides in the afternoon; but near meridian the rays fall upon a few points only, and even upon these with very great obliquity. Thus at the hours of greatest general illumination the wall is most obscure and the abnormal effects are then presented most forcibly. They give rise to strange delusions. The rocks then look nearly black, or very dark grey, and covered with feebly shining spots. The haze is strongly luminous, and so dense as to obscure the details already enfeebled by shade as if a leaden or mercurial vapor intervened. The shadows antagonize the perspective, and everything seems awry. The lines of stratification, dimly seen in one place and wholly effaced in another, are strangely belied, and the strata are given apparent attitudes which are sometimes grotesque and sometimes impossible.

Those who are familiar with western scenery have, no doubt, been impressed with the peculiar character of its haze—or atmosphere, in the artistic sense of the word—and have noted its more prominent qualities. When the air is free from common smoke it has a pale blue color which is quite unlike the neutral gray of the east. It is always apparently more dense when we look towards the sun than when we look away from it, and this difference in the two directions, respectively, is a maximum

near sunrise and sunset. This property is universal, but its peculiarities in the Plateau Province become conspicuous when the strong rich colors of the rocks are seen through it. The very air is then visible. We see it, palpably, as a tenuous fluid, and the rocks beyond it do not appear to be colored blue as they do in other regions, but reveal themselves clothed in colors of their own. The Grand Cañon is ever full of this haze. It fills it to the brim. Its apparent density, as elsewhere, is varied according to the direction in which it is viewed and the position of the sun; but it seems also to be denser and more concentrated than elsewhere. This is really a delusion arising from the fact that the enormous magnitude of the chasm and of its component masses dwarfs the distances; we are really looking through miles of atmosphere under the impression that they are only so many furlongs. This apparent concentration of haze, however, greatly intensifies all the beautiful or mysterious optical defects which are dependent upon the intervention of the atmosphere.

Whenever the brink of the chasm is reached the chances are that the sun is high and these abnormal effects in full force. The cañon is asleep. Or it is under a spell of enchantment which gives its bewildering mazes an aspect still more bewildering. Throughout the long summer forenoon the charm which binds it grows in potency. At midday the clouds begin to gather, first in fleecy flecks, then in cumuli, and throw their shadows into the gulf. At once the scene changes. The slumber of the chasm is disturbed. The temples and cloisters seem to raise themselves half awake to greet the passing shadow. Their wilted, drooping, flattened faces expand into relief. The long promontories reach out from the distant wall as if to catch a moment's refreshment from the shade. The colors begin to glow; the haze loses its opaque density and becomes more tenuous. The shadows pass, and the chasm relapses into its dull sleep again. Thus through the midday hours it lies in fitful slumber, overcome by the blinding glare and withering heat, yet responsive to every fluctuation of light and shadow like a delicate organism.

As the sun moves far into the west the scene again changes, slowly and imperceptibly at first, but afterwards more rapidly. In the hot summer afternoons the sky is full of cloud-play and the deep flushes with ready answers. The banks of snowy clouds pour a flood of light sidewise into the

shadows and light up the gloom of the amphitheaters and alcoves, weakening the glow of the haze and rendering visible the details of the wall faces. At length, as the sun draws near the horizon, the great drama of the day begins.

Throughout the afternoon the prospect has been gradually growing clearer. The haze has relaxed its steely glare and has changed to a veil of transparent blue. Slowly the myriads of details have come out and the walls are flecked with lines of minute tracery, forming a diaper of light and shade. Stronger and sharper becomes the relief of each projection. The promontories come forth from the opposite wall. The sinuous lines of stratification which once seemed meaningless, distorted, and even chaotic, now range themselves into a true perspective of graceful curves, threading the scallop edges of the strata. The colossal buttes expand in every dimension. Their long, narrow wings, which once were folded together and flattened against each other, open out, disclosing between them vast alcoves illumined with Rembrandt lights tinged with the pale refined blue of the ever-present haze. A thousand forms, hitherto unseen or obscure, start up within the abyss, and stand forth in strength and animation. All things seem to grow in beauty, power, and dimensions. What was grand before has become majestic, the majestic becomes sublime, and, ever expanding and developing, the sublime passes beyond the reach of our faculties and becomes transcendent. The colors have come back. Inherently rich and strong, though not superlative under ordinary lights, they now begin to display an adventitious brilliancy. The western sky is all aflame. The scattered banks of cloud and wavy cirrhus have caught the waning splendor, and shine with orange and crimson. Broad slant beams of yellow light, shot through the glory-rifts, fall on turret and tower, on pinnacled crest and winding ledge, suffusing them with a radiance less fulsome, but akin to that which flames in the western clouds The summit band is brilliant yellow; the next below is pale rose. But the grand expanse within is a deep, luminous, resplendent red. The climax has now come. The blaze of sunlight poured over an illimitable surface of glowing red is flung back into the gulf, and, commingling with the blue haze, turns it into a sea of purple of most imperial hue—so rich, so strong, so pure that it makes the heart ache and the throat tighten. However vast the mag-

nitudes, however majestic the forms, or sumptuous the decoration, it is in these kingly colors that the highest glory of the Grand Cañon is revealed.

At length the sun sinks and the colors cease to burn. The abyss lapses back into repose. But its glory mounts upward and diffuses itself in the sky above. Long streamers of rosy light, rayed out from the west, cross the firmament and converge again in the east, ending in a pale rosy arch, which rises like a low aurora just above the eastern horizon. Below it is the dead gray shadow of the world. Higher and higher climbs the arch, followed by the darkening pall of gray, and as it ascends it fades and disappears, leaving no color except the after-glow of the western clouds and the lusterless red of the chasm below. Within the abyss the darkness gathers. Gradually the shades deepen and ascend, hiding the opposite wall and enveloping the great temples. For a few moments the summits of these majestic piles seem to float upon a sea of blackness, then vanish in the darkness, and, wrapped in the impenetrable mantle of the night, they await the glory of the coming dawn.

CHAPTER IX.

THE AMPHITHEATERS OF THE KAIBAB.

The spring on the summit.—Tapeat's Amphitheater.—Descent of the cañon wall.—Surprise Valley.—Powell's Plateau.—The Hidden Spring.—Shinumo Amphitheater.—Muav Cañon.—Hindoo Amphitheater.—Milk Spring again.—Shiva's Temple.—The central chain of parks and the drainage.—Thompson's Spring.—The Transept.—Bright Angel Amphitheater.—The Lagoon.—Ottoman Amphitheater.—Alcoves and buttes.—Cape Royal.—The Cloister buttes.—Cape Final.—Vishnu's Temple.—The head of the Grand Cañon.—The monocline and the exposures of the Silurian.—The junction of the Little Colorado.—The great unconformity at the head of the Grand Cañon.—The monoclines and faults south of the chasm.

In the present chapter I shall describe briefly the portions of the Kaibab boundary which front the great chasm, noting the more important amphitheaters and prominent objects of interest. It would be the more intelligible if the reader have before him the several sheets of Mr. Bodfish's map of the southern portion of the Kaibab. Let us begin this tour at the westernmost part of the plateau represented in the northwestern sheet of the map.

In order to reach that point, it is best to start from a little spring in the western portion of the Kaibab, which the surveying parties have always called by its Indian name, *Parusi-wompats.* The traveler who has never visited it would scarcely be able to find it without a guide. It is securely hidden in a shallow ravine, which has nothing to distinguish it from hundreds of other ravines upon the broad platform. But the trail being known it is easily reached by a few hours' ride through the forest, either from the Big Spring in Stewart's Cañon or from De Motte Park. A more delightful camping place in summer or early autumn cannot be found. The grand old pines, the large graceful spruces, and pale-green aspens are abundant, but not too dense; the grass is knee-deep and swarming with gay flowers; the ground is dry and firm. The ravine rambles away as an open glade in the forest, and soon winds out of sight. Beneath a clump of spruces the spring sends forth a slender thread of clear pure water, almost icy cold,

and a few yards from its fountain the waters disappear. If any one would know how great a luxury pure cold water is, let him drink of Parusiwompats,* and afterwards pitch his tent by the water-pockets of the Kanab and Uinkaret deserts. Leaving the spring at sunrise and moving northwestward through an undulating forest-clad country, a ride of about three and a half miles brings us to an angle of the

TA-PEATS AMPHITHEATER.

It is one of the first order of magnitude, and is eroded back about eight miles into the Kaibab mass from the angle where the river bends to the west to flow through the Kanab division of the cañon. We come upon it suddenly and in a moment are gazing down into fearful depths or across at cliffs piled on cliffs. Upon the southern side is the large isolated mass called Powell's Plateau (of which we shall see more hereafter), forming the southern wall of the amphitheater. In the middle of the abyss is planted one of those gigantic buttes so characteristic of the Kaibab scenery. It is very noble in its proportions and beautiful in its profiles. A remnant of the cherty limestone about 200 feet thick carved into some shape, which is quite striking though nameless, serves as a finial to the pagoda. Below it the curved profiles sweep down 1,600 feet, and then plunge precipitously below the Red Wall some 1,400 to 2,000 feet more. The width of the amphitheater measured parallel to the general course of the river is about nine miles. Its back wall on the east is nearly straight in its general trend, but in detail it is deeply scored by notches. At the bottom runs the Tapeats Creek, a considerable stream of clear water fed by many large springs bursting from the lower portions of the great Kaibab wall. Though it is wrought upon a grand scale, and though, in comparison with ordinary plateau scenery, this profound valley is unspeakably impressive, it is inferior in diversity, and in the number of commanding objects displayed, to those further to the southeastward. It occupies a middle ground between

* I am unable to give the full translation of this name. *Parush* means flowing water; the last word is probably associated with some mythical ideas of which Indians rarely speak to white men.

the complicated features of the Kaibab division and the simpler characteristics of the Kanab division.

Upon the northern side of this amphitheater there is a trail by which it is practicable to descend from the upper crest to the brink of the river. It is a long and devious route, requiring a whole day's journey to get down and nearly two days to ascend. In the year 1876 a rumor was circulated that gold had been found in the sands of the river, and it gained credence enough to attract a number of the restless people who tramp the deserts of the far west in pursuit of—they know not what. With considerable labor and danger this trail was built and used long enough to satisfy those who went there that they had been deceived. In 1880 it was again used by the parties of this survey to reach the river and make a series of barometric observations. As an instance of what the explorer must expect who attempts the feat of scaling these mighty walls the features of this route are worthy of description. It may be added that there is no other known place promising any better facilities for constructing a pathway down the cliffs, and probably also none so good.

From the crest of the wall we descend at once a notch in the cherty limestone so steep that it seems at first impracticable. The gradient is only a little less than the angle of repose, but the roughness of the rock produced by the weathering out of the cherty nodules gives good holding ground, and with care the way is not dangerous. By zigzag courses we at length descend about 700 feet and reach the summit of the cross-bedded sandstone. There are two formations in the Grand Cañon series which oppose the chief obstacles to the ascent or descent of the escarpments. The worst is the Red Wall and the other is the cross-bedded sandstone. Both present cliffs which are rarely broken down into slopes. Their edges may be followed for scores of miles without finding a practicable passage. The Red Wall is particularly inexorable. In all the Kaibab division of the chasm only three or four places are now known which offer any hope of a passage of this formation. The cross-bedded sandstone is more frequently beveled down, but even in this mass the breaks are few and far between. The only locality at present known where both formations present breaks within a day's journey of each other is the one we are describing.

Here a rain gully has cut a steep trough in the sandstone which, by its very roughness, permits us to descend, or rather slide down, at moderate risk. With one man to pull on the halter and two to push, each animal may be launched on its adventurous journey. The sandstone is scoured into a series of maximum and minimum slopes, all of them bare rock, and by sliding helplessly down the former and checking themselves upon the latter, the poor beasts escape perdition. The thickness of the sandstone thus traversed is about 350 feet. At its base we find the lower Aubrey, which presents a less difficult aspect. It now remains to find the passage of the Red Wall, which is ten miles distant, and in the mean time we must descend a thousand feet of sandstones which make up the lower Aubrey. These consist of innumerable beds, varying in thickness from five feet to fifty, each presenting its own ledge and talus. The ledges are often beveled and notched by rain gullies, and wherever the way seems easiest we alternately travel along the talus and slide or scramble down the broken ledge to the next talus below. For several hours the journey consists of this kind of travel. Here the trail heads some offshoot of a great lateral gorge, there it rounds some lofty promontory. Often the shelf on which we move narrows to a mere fillet with imminent rocks above and destruction below. Had not the trail been already chosen we should find the shelves gradually vanishing, the ledge below becoming a single face with the ledge above. As it is the trail needed in many places to be built up to give a narrow tread along some projecting shoulder, where the packs brush the rocks as the mules pass by. At length it becomes steeper, the ledges more frequent and higher, and the way grows somewhat alarming. A single inadvertence, the slightest accident, sends man or beast to the great unknown.

At length we reach the summit of the Red Wall limestone and a vertical cliff 1,200 feet high is below us. Here the trail doubles on itself and turns back at a lower level, following the brink of the cliff for three miles. At the end of this stretch is the summit of a steep but practicable slope across the Red Wall. Again the trail doubles in its course and a rapid descent of 2,000 feet brings us with no further danger to Surprise Valley.

We seem to be in a *cul de sac*. On the right is the great Red Wall preci-

pice, on the left a lofty ridge of the same, and in front is the great precipice again. Out of a lateral chasm on the right there flows a large creek of water, clear as crystal, and dashing merrily along its rocky bed. It emerges from a cavern in the cliff and passes right across the lower end of the valley; but whither does it go? It seems to enter the inclosing ridge on the left. Following the stream a few hundred yards the ridge is seen to be cleft transversely by a cut 50 or 60 feet wide and 700 or 800 feet deep. The cleft winds out of sight into its mass. Leaving the animals and entering its opening there is seen to be a deeper and narrower cleft about 12 feet wide into which, by a succession of cascades, the brook plunges. At the top of the lower and narrower cleft is a shelf, along which we may walk. The width of this shelf contracts and the walls begin to overhang. As we progress it becomes only three or four feet wide and the overhang is so low that we must creep on hands and knees. Beside us is the fissure, and the reverberations of the water come up from unseen depths which appear by the sound to be great. Soon the shelf widens again and the roof rises higher so that we may walk erect. A few hundred yards beyond we emerge into full daylight again upon the brink of a cliff about 450 feet high. At the bottom flows the Colorado River. A little to the west the cliff is shattered, and there we may descend to the water's edge and refresh ourselves. Here the river is about to flow out of the "granite," for the gentle dip of the whole stratigraphic system towards the west carries the horizons downward at a rate more rapid than the fall of the river. Here, too, is the beginning of the Kanab division of the Grand Cañon.

There is little here of interest to the geologist beyond what will be, or what has been, described in this work in more general terms. I have indulged in this digression to convey graphically an idea of the cañon wall and to indicate the difficulties which attend an examination of points within the chasm. Let us, therefore, return the way we came.

Leaving Parusi-wompats Spring, a faint trail leads to the southwestward, winding through the forest and across ravines and gulches. A ride of two or three hours brings us once more to the brink; here is a wide gap, separating the main Kaibab platform from a large outlying mass named

POWELL'S PLATEAU.

This gap is a saddle or col between the Tapeats amphitheater on the north and a vast lateral gorge on the south, known as the Muav Cañon. Erosion has eaten completely through the upper beds of the isthmus which formerly connected Powell's Plateau with the mainland, removing therefrom about 1,200 feet of strata. The saddle thus formed is therefore 1,200 feet below us, and to reach the outlying plateau it is necessary to descend into and cross the intervening gap. A curious phenomenon is presented here. On the spot where we stand it would hardly be seen, but it is very conspicuous from points eight or ten miles north or south. One of the branches of the West Kaibab multiple fault cuts right across the isthmus from north to south, and presents a relation similar to those presented in some parts of the Hurricane, Sevier, and other faults. The beds upon the western side of the fault flex downwards at a considerable angle as they approach the fault-plane. This of itself is a very common thing, and is exhibited so frequently in the faults of the Plateau Province that we have come to regard it as one of the characteristic features of its displacements. The peculiarity here is that at the distance of less than a mile west of the fault the beds have come back to the same position they would have occupied if no fault had occurred. From the summit of the Kaibab there is a sensibly uniform dip of the beds to the southwestward, continuing across and beyond Powell's Plateau, and even beyond the river, the inclination being about $1\frac{3}{4}°$. This fault comes in as a purely local interruption, affecting the beds in its immediate vicinity on the west side of the fault-plane and having no effect upon them a little distance from it. This singular mode of displacement is extremely perplexing when we come to inquire into the nature of the causes which have produced faults, and reminds us very forcibly how ignorant we are of those causes, and how inapplicable are all theories hitherto advanced to explain them. This same dislocation continues both north and south of the gap. On the northern side of the Tapeats amphitheater the beds and general platform have been dropped by the fault, and its effect is continuous west of the fault-plane. South of the gap the relation of the beds is apparently the same as at the gap itself, so

far as could be made out for a distance of seven or eight miles. But south of the Grand Cañon a short and rather small monoclinal flexure is seen in the wall, in which the platform west of the fault is actually higher than that on the east. It is believed to be a continuation of the same displacement, but in the confused mass of objects in the great chasm the continuity has escaped identification. Little doubting this continuity, I may cite this case as an instance of the complete reversal of the throw of faults as we trace them along their trend.

The descent into the Muav saddle is very steep, and, though hardly dangerous, requires caution and the steadiest and best trained pack animals to go safely past some points. At the bottom a fine camp may be made beneath the yellow pines, and good water may be obtained from a spring about a quarter of a mile away, issuing from a ledge of the lower Aubrey sandstone. No permanent water is found on Powell's Plateau, and whatever is required for the visitor there must be brought from this spring. The ascent on the other side of the gap is steep and difficult, but requires nothing more than the ordinary strength of youthful limbs and healthy lungs. Reaching the platform above, it is quite like that of the Kaibab, beautifully forest-clad and undulating, with shallow ravines and intervening ridges. Once away from the immediate vicinity of the brink, there is nothing to indicate the proximity of stupendous scenery.

Powell's Plateau is about five and a half miles in length and two miles in width. It declines gently in altitude from northeast to southwest, the latter extremity being about 500 feet lower than the former. This declension is part of the general slope which descends from the summit of the great Kaibab mass to the central part of the Kanab and Colorado platforms, at a rate not often exceeding 150 feet to the mile, and usually less. The situation of this outlying butte—for such it may be very properly considered—is directly in the course pursued by the Colorado in the Kaibab division. As the river approaches its base it makes a sudden detour to the west, and skirting around its furthermost point it winds back to the northeast until at the mouth of the Tapeats amphitheater it reaches the head of the Kanab division. There it bends once more to the west-southwest, and holds that course for nearly sixty miles. Thus the plateau lies in the pro-

longation of the median line, and immediately athwart the course of the grandest part of the Grand Cañon, and as we reach the southern brink there bursts upon the view a scene which rivals that at Point Sublime. In truth, many will no doubt consider it as the grandest in the cañon, and in certain respects it certainly is so, though I must, for my own part, give a slight preference to that of Point Sublime. It is far more picturesque than the latter and is less panoramic. The objects are grouped about a central point, or rather axis, to which they are seen to be tributary. A stretch of the river six miles long is in full view, flowing in the dark depths of the granite more than a mile below. The reason alone tells us it is water; to the eye it is a fixed, motionless, slender thread—a narrow streak of color—a ghost. It comes, we know not whence—seemingly from the bowels of the earth, and it seems to enter them again beneath our very feet. On either side spring up the gigantic buttes lined with richest tracery and molded in graceful patterns. The great promontories from either wall stretch out towards it, presenting terminal gables or sharp spurs bristling with minarets and needles. A perspective of fifty miles is before us of twin palisades, too grand for comprehension, of infinite diversity, and amazing sculpture. In the interspace are numberless structures of wonderful forms and colossal magnitudes.

The scene here in comparison to that of Point Sublime may be likened to the vista of a grand avenue of the most stately and imposing structures viewed from the end of the street, while from Point Sublime the standpoint is analogous to one from a projecting pediment situated mid-length of the avenue, where we may with equal effect look up or down and across to noble structures on the other side. At Powell's Plateau the view is more picturesque and more systematic. In grandeur it is about equal. But the defect which usually mars all cañon scenery is here more pronounced. It is the false perspective, the flattening of objects through want of gradations in tones and shades, and the obscurity of form and detail produced by the great distances and hazy atmosphere. But under proper lights and conditions of the air these defects may, on rare occasions, be dispelled.

The main wall on the southern side of Powell's Plateau descends to the river with more than usual precipitation. From above, little of it can

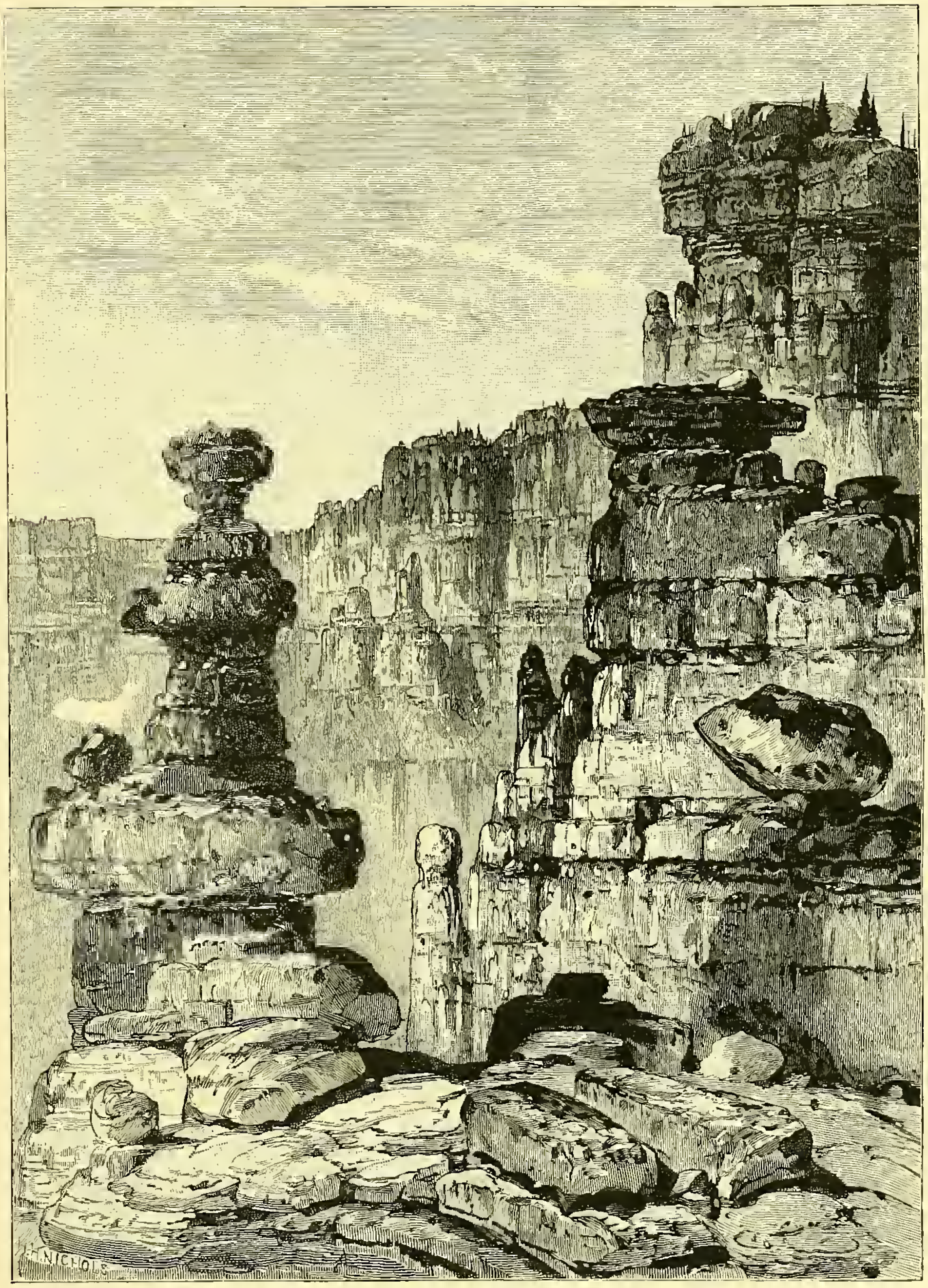
be seen, but from distant points to the southward it is very conspicuous for its splendid alcoves, buttresses, and cusps, which are carved upon a scale of grandeur somewhat unusual even for the Grand Cañon. Nothing can surpass the magnificence of the Red Wall group along the façade. Its entire bulk is presented in a single plinth, which is recessed by alcoves or deep panels 1,200 to 1,500 feet wide, with finely sculptured buttresses intervening between them. Very ornate also are the rows of pinnacles carved out of the cherty limestone forming the summit stratum of the plateau. These are well displayed upon the eastern crest. They are from 180 to 200 feet high and stand about 100 feet apart.

Towards the west, Powell's Plateau divides into a series of slender promontories pointing towards the river, and several of these have detached buttes just beyond the main cusps. The view from this end is also instructive as well as very grand. The river here is gradually passing out of and above the granite, and the topography of the cañon passes by a gradual transition from the features peculiar to the Kaibab to those of the Kanab division. The Red Wall group is much less eroded than in the heart of the Kaibab division, but much more so than in the Kanab. The great middle terrace of the Kanab division begins to appear. It is much cut up by side gorges and minor amphitheaters, but the greater part of its mass still remains. Towards the west and northwest these lateral gorges in the Red Wall group become fewer and smaller, while towards the southeast they become more numerous, deeper, and wider, until only the cloister buttes remain. All this is indicative of a more advanced stage of the general erosion in the Kaibab than in the Kanab division. This in turn may be traced directly to the greater altitude and greater rainfall of the former with a correspondingly greater efficiency of the eroding agents and causes.

On the return from Powell's Plateau to the Kaibab it will be interesting to look into the great gorge which has received the name of Muav Cañon. It heads at the saddle and extends southward, opening into the channel which drains the next great amphitheater. As we look into it we are in a measure shut out from the view of the immense spectacle displayed in the main chasm, and the mind is not under the sway of those overwhelming effects which the panoramic scenery of the cañon always pro-

duces, and is not quite so completely overpowered by a vastness which it cannot begin to realize. The Muav is relatively only a little nook—a mere detail like scores of others, which open directly into the chasm itself or into the greater amphitheaters, and which are lost or unnoticed in the multitude. Yet as we view it apart from the whole we are still oppressed with its magnitude. Its walls are a mile in height and very abrupt. The taluses are unusually narrow and the precipices more predominant than in more typical profiles. The lines of stratification, always clear and bold in the cliffs of the chasm, are disclosed with more than common emphasis and in great number. Their scalloped contours, rigorously parallel, winding gracefully in and out, are projected in curious figures by the perspective and give rise to many illusions. As we stand in the saddle and look down into the abyss beneath, all sense of absolute magnitudes is quite lost. The trees dwindle to shrubs and then to minute flecks; the fallen blocks, as big as cottages, fade away and blend together in a minutely granular patch-work of shades and warm colors, and far down in the lower depths the eye can recognize nothing but a playground for the imagination. Above us on the crest-lines are the rows of pinnacles. As we stood beside them a few hours ago and looked up to the quaint, curious knobs upon their summits we felt very much as we might when looking up at the Bunker Hill Monument. As we see them now ranging away into the distance they seem altogether too tiny and trifling to serve as appropriate decorations for these monstrous façades. But the Muav is only a trifle!—a little piece of by-play on which we may condescend to bestow a passing look of pleasure as we hasten on to grander and mightier scenes!

Climbing out of the gap, we reach the Kaibab platform again. It is not necessary to return to Parusi-wompats, which is in a different direction to that which we wish to pursue. Moving southeastward about three miles, we come to the brink of a large surface ravine, cut to the depth of about 400 feet, and with steep sides. It is one of the largest and deepest in the southern portion of the Kaibab, though in other respects it is quite similar to the others. A trail leads to the bottom of it, and a small spring is found about 400 yards further down the ravine. We named it the Hidden Spring,



PINNACLES.—KAIBAB.

for it is quite deftly concealed upon the left bank, and were it not for the beaten track our parties have made, it would not be readily found by future travelers. From this point the distance by trail to Point Sublime is about 18 miles, and if it is desired to reach that promontory from here it will be necessary to carry water in kegs. But a chapter has already been devoted to a description of the cañon as seen from Point Sublime, and our journey should be to the next watering place to the southeastward. From the Hidden Spring, however, we may make journeys on foot to numerous points overlooking the chasm. Ascending the steep sides of the ravine, a walk of two or three miles to the westward will bring us to crest of the

SHINUMO AMPHITHEATER.

It is one of the first order of magnitude, and though its area is less than that of the Tapeats amphitheater, its scenery is much more imposing. We look across the Grand Cañon to the country beyond. Between us and the opposite wall is an interval of 12 miles, thronged with those magnificent masses and intricate details which characterize the Kaibab division. A plexus of drainage channels heading all around the base of the upper encircling walls unite in a short trunk channel which enters the Colorado. Each branch and filament has cut a lateral chasm of immense depth, and between the gorges rise the residual masses, in the form of buttes. Some of these are gorgeous pagodas, sculptured in the usual fashion, and ending in sharp finials at the summit. Others are the cloister buttes with wing-walls and gables, panels and alcoves. All are quarried out upon a superlative scale of magnitude, and every one of them is a marvel. The great number and intricacy of these objects confuse the senses and do not permit the eye to rest. The mind wanders incessantly from one to another, and cannot master the multitude of things crowded at once upon its attention. There are scores of these structures, any one of which, if it could be placed by itself upon some distant plain, would be regarded as one of the great wonders of the world. Yet here they crowd each other, and no one of them

predominates sufficiently to form a central point in the picture. Still, the total effect is quite commensurate with that experienced in the choicest standpoints from which the cañon may be viewed. The power and grandeur of the scene is quite beyond description.

Leaving the Hidden Spring our next objective point is the Milk Spring, already spoken of as lying upon the route from De Motte Park to Point Sublime. Our base of operations, it will be perceived, is always some watering place, and such places are few and not often conveniently situated. The distance to the Milk Spring is about 14 miles by trail through the forest. Moving up the large ravine a distance of about 4 miles from the Hidden Spring, we at length leave it upon its southern bank. The way is delightful. It lies through a succession of little parks, and along the courses of the ravines, with open forest on either hand. The drainage channels here run to the southwest, heading near De Motte Park, and our route crosses them. None of them present any notable obstacles to travel, for their banks are rarely precipitous or even steep. On the way we come once more near the brink of the Shinumo Amphitheater, for a ravine runs past a large alcove near the head of it, and by ascending the bank it breaks upon the view with a suddenness which is quite startling The traveler might pass this point many times without suspecting his proximity to such stupendous scenery, and unless duly advised would suppose himself far away from the brink in the depths of the forest.

From the Milk Spring we may at our pleasure revisit Point Sublime. The distance is only ten or eleven miles by an easy trail, which we shall follow here far enough only to note another grand amphitheater—or rather a pair of them. The trail comes suddenly upon the brink about five miles from the spring. One of the tributaries of the Colorado between Shiva's Temple and Point Sublime forks about three miles from the river, and each fork is in the bed of a mighty basin, the two being separated by a long and singularly slender promontory, which is in reality a large cloister butte. We may regard the two basins either as two or as branches of a single amphitheater. Taking the latter view of the arrangement we have named the whole as the

HINDOO AMPHITHEATER.

It is eroded back from the river a distance of about ten miles. The two branches are parallel, and each is about three miles in width. They are therefore much narrower than the Tapeats or the Shinumo, and strikingly different in plan. They appear from above as immense cañon-like gorges opening far away into the central or main avenue of the Grand Cañon. Their upper ends are bounded by circular walls which descend at once cliff below cliff to a depth of about 3,600 feet. Thence towards the river they grow deeper at the rate of over 200 feet to the mile. The walls are finely sculptured and richly colored. As we look down the long vista and out into the central chasm beyond we see the great throng of giant buttes and temples, vast pyramids and towers ornamented with rich tracery, all clustered together so thickly that they seem to crowd each other. At the lower end of the eastern branch, or near the confluence of the two branches, rises the largest and perhaps the most conspicuous of all the pagodas, Shiva's Temple. It is more than a mile high, and remarkably symmetrical in its profiles. In this butte the entire local Carboniferous series is preserved. Its summit is a horizontal tablet of the cherty limestone nearly a mile in width occupying a horizon sensibly even with the summit of the main plateau. Around it are gorges of immense depth into which the façades of the temple descend by a succession of cliffs and taluses. The rain sculpture in the edges of the strata is quite ornamental, and the detail forms repeat themselves in characteristic ways in every member.

In these amphitheaters we cannot fail to be much impressed with the intricate and yet systematic manner in which the ground plan of the walls is laid out. Great alcoves and cusps are formed, and wherever the wall makes a turn it is by a well-rounded inward curve or by a sharp cusp-like projection. The architectural details are always striking, and by their profusion and richness suggest an Oriental character.

The long and rather wide promontory ending at Point Sublime separates the Hindoo Amphitheater from the Shinumo. It is interesting here to note the peculiar relation of the surface ravines of the Kaibab to these mighty excavations. In truth, it seems at first as if the surface ravines had

no definite or assignable relation to them in any respect whatever. One very marked ravine comes from the summit overlooking Little De Motte Park, and runs along the middle of the promontory which ends at Point Sublime and terminates at the brink. No ravine enters the Shinumo at its head, but two enter it at the sides. There is no ravine entering the head of the western branch of the Hindoo, but a rather deep one enters the head of the eastern branch. A conception of the real state of the case may, perhaps, be gained by recalling the fact that these amphitheaters were originally narrow cuts produced by corrasion, and subsequently widened by the weathering of the edges of the strata thus exposed. The walls recede by waste away from the axis of the cut, and sooner or later a ravine here and there is tapped laterally by the receding wall wasting backwards across its course. Thus we often find an old ravine suddenly cut off on the brink of an abyss, and the continuation of the same ravine is seen upon the other side of the amphitheater. Quite probably, at some very early stage in the excavation of the Grand Cañon and its lateral gorges, the amphitheaters were merely the lower courses of the stream beds which constitute the Kaibab drainage system. But these streams dried up and the enlargement of the chasms went on in a measure independently of the distribution of the surface ravines. Here and there a ravine shows that it has maintained the old relation and enters the amphitheater at its head. Such ravines are almost always the largest ones, and they notch the wall of the amphitheater to a depth of 400 to 500 feet. They may in such cases possibly be regarded as the main channels of the lateral gorges. But usually the surface channels end anywhere upon the brink in seeming caprice as to choice of locality. If we could restore the mass which has been removed in the Grand Cañon we might very probably find them gathering together into a series of ordinary tributaries, constituting a limited number of district drainage trees, the trunks of which are the existing channels at the lower ends or openings of the great amphitheaters.

From the Milk Spring we may also make a journey southward to the end of the great promontory which forms the eastern wall of the Hindoo Amphitheater. The scene here presented is of the same general character as that from Point Sublime. It is not quite so satisfactory, however, because

AN ALCOVE.—IN THE RED WALL.—KAIBAB.

the mighty mass of Shiva's Temple is interposed, and hides from view a large part of the panorama. It has, however, some advantages, for it gives us probably the clearest view we can obtain of the stupendous character of the side gorges. This aspect of the great butte, Shiva's Temple, is on the whole decidedly marred by too great proximity. So vast a mass can be seen advantageously only from a considerable distance. Here it is only a little more than a mile away, and but a small portion of it is visible.

From the Milk Spring we journey eastward. Two or three miles from the spring we descend into a very broad valley, forming a large open park, with a few scattered groves of spruce, aspen, and pine, but mainly clear meadow, densely carpeted with grass and flowers. It is one of a long chain of wide parks, of which the largest is De Motte's. The one we are now entering is a few miles south of Little De Motte. It is conspicuously different in its features from the ordinary drainage channels which cover the surface of the Plateau, being very much wider. All of the others are narrow. Here the width is about two miles. Upon its western bank no ravines enter it, but those which head upon the summit flow away from it to the westward and southwestward. A few short ravines come into it upon the eastern side. This valley is a dividing furrow, completely separating the drainage of the Kaibab summit into two independent systems and areas. They never interlace or show any relation to each other. This broad valley on the summit of the Plateau completely separates them, and receives absolutely nothing from the area west of it, and almost nothing from the area east of it.

At the bottom of the valley we find outcrops of the cross-bedded sandstone. Inasmuch as the cherty limestone is found upon the heights overlooking the valley, and as the difference in altitude is just equal to the thickness of strata between the two geological horizons, we may safely conclude that the valley is the work of erosion, and is not due to the dislocation and dropping of a wedge of strata, as was at one time suspected

Crossing the park and ascending the heights upon the east, we once more descend into a rather deep ravine of the usual type. Upon its bank the trail passes by a small trickling fountain, known as Thompson's Spring. A basin has been dug and made water-tight by our parties to save the scanty supply of precious liquid which issues from it. The flow, though

extremely feeble, is unfailing and the water excellent. The Milk Spring, though very much more copious, has been known to fail in very dry seasons. Thompson's Spring is an important camping place in the study of the extreme southern portions of the Kaibab, for it is the last spring of water in that direction which can be depended upon. A good trail leads to it from De Motte Park, the distance being about 17 miles.

From this point we may visit several interesting localities. Following downwards the main ravine about five miles we find it at length betraying evidence that it is near the brink of some amphitheater. Climbing the steep bank to the main platform 300 feet above, we move towards the southwest, and in half an hour more are upon the verge of one of the finest and perhaps the most picturesque of the gorges in the whole Kaibab front. It is a tributary to the Bright Angel Amphitheater, and has been called by us The Transept. Though only of the second or third order of magnitude among the lateral excavations along the Grand Cañon, it is far grander than Yosemite. At the very head of the gorge the walls plunge downwards at once more than 3,000 feet. As the gorge deepens towards its junction with the main amphitheater the aspect of the lateral walls, as they recede from us, becomes most imposing. The details of their sculpture are very beautiful and thoroughly systematic, and every characteristic is sustained throughout their whole extent. The entire length of the chamber is seen in perspective. Beyond its opening we see the grandeur of the central cañon with butte beyond butte, and the vast southern wall of the main chasm in the background fifteen miles away. To many spectators the dominant thought here might be that this stupendous work has been accomplished by some intelligence akin to the human rather than by the blind forces of nature. Everything is apparently planned and cut with as much definiteness of design as a rock-temple of Petræa or Ellore.

Another interesting locality is the cape where the Transept joins the main amphitheater. It is easily reached from Thompson's Spring. Here is disclosed the

BRIGHT ANGEL AMPHITHEATER.

Altogether it is perhaps the finest of those of the first order. It is the longest and deepest of any, and is also the narrowest. Its length is about fifteen miles, its width varies from two to three miles, and through the greatest part of its extent it is cut deeply into the granite. A fine large creek of clear water flows along its bottom and enters the Colorado. Its walls, more than 5,000 feet in height, are majestic in the extreme, and present the noblest forms. Upon its southern side and along the lower portion the promontory which separates it from the amphitheater next beyond has been carved into a cloister butte, which is one of the finest of its class. Upon its thicker parts are planted pagodas, which are terminated above by sharp finials. The projecting wings include grand alcoves between them, which toward sunset are filled with a "dim religious light," commingled with a tenuous haze suggestive of the smoke of incense. The walls which encircle these recesses ascend in awful grandeur, as rich in sculpture as a Gothic cathedral. Beyond is the throng of temples and the dominant façade of the further cañon wall. It is a repetition of the scenery which overpowers us at Point Sublime, unchanged in style and undiminished in grandeur. There are many spots, and this is only one of them, where comparisons seem no longer possible. Each is far beyond the power of the faculties to comprehend it, and no one of them greatly exceeds the others. They differ as the turns of the kaleidoscope differ from each other. But they never grow monotonous. When the mind has once wrestled with this scenery it feels its own insignificance, but it does not grow listless, nor lose its enthusiasm. It is rather disciplined and brought into a calmer and better regulated mood and the better fitted to enjoy it.

Thompson's Spring is also the starting-point from which to visit the extreme southern portion of the Kaibab. It is the southernmost spring which can be depended upon to furnish good water. There is a lagoon further south, which in ordinary seasons retains water through the summer, but the quality is by no means of the best, and it is desirable to carry a supply in kegs from the spring. Ascending Thompson's ravine about a mile, we leave it by a side gulch and pass over two broad ridges, keeping a

general course towards the east. It is necessary to make a detour in order to head the Bright Angel Amphitheater, which is very long, and is eroded so far back into the plateau that its upper end is only a little more than a mile from the main eastern flank of the plateau, and the portion of the Kaibab south of it is almost isolated from the main mass. At length the trail leads down into a ravine of unusual depth, with very steep banks. A few hundred yards below it plunges into the vast depth of the great amphitheater. There is a very small spring* in the bottom of the ravine a few hundred yards above the point where the trail reaches the bottom, but it is hardly available, and yields but a very few gallons per day. Climbing the southern bank, we once more reach the summit platform, and a mile further on we find a large lagoon. Its water is stagnant and strongly impregnated with vegetable matter, but it is incomparably better than that which we are sometimes compelled to use at the pockets in the desert. If a protracted stay is made at the south end of the Kaibab, there is no alternative but to send back to this lagoon for a supply for camp purposes and to sustain the animals. In very dry seasons its contents are wholly evaporated before the summer or early autumn is over. The picturesqueness of the spot, however, is some compensation for the inferiority of the water. Very lovely is the sylvan scenery of the Kaibab summit. It never fails. Wherever we go the grand old trees are above us and the grassy lawn beneath our feet. The ground is unencumbered with undergrowth, and the beautiful vistas of open parks, winding glades, and vanishing avenues of tree trunks, the long nodding grasses, and flowers, invite the fancy to wander forever in Paradise.

From the lagoon our course is nearly southward. Crossing several ravines athwart our path, we at length follow downwards the course of one leading southwestward. The trail "scatters" and is finally lost, and our way is literally in the pathless woods. As the ravine grows more rugged, and deepens and narrows rapidly, we interpret its meaning to be a near approach to its termination at some lateral chasm. Ascending its left bank to the upper platform, a ride of half a mile brings us to the verge of the

*I have been particular to note the locations of the few springs on the Kaibab, because they are of the utmost importance to the traveler.

OTTOMAN AMPHITHEATER.

It is one of the first order of magnitude with several branches, and about as grand as any. It is notable for its magnificent display of buttes. These wonderful structures seem to grow more picturesque, more ornate, and more numerous as we approach the head of the Grand Cañon, and, though none of them are of such vast dimensions as Shiva's Temple, they are still of enormous magnitude and much more elaborately designed and more sumptuously carved. Perhaps the butte-work has it climax here, though it is well developed everywhere in the Kaibab division. The façades are exceedingly tortuous and full of great alcoves. The lavish wealth of this kind of display is its most remarkable feature. Very impressive, too, are the branch amphitheaters. These features are more simple and concentrated when considered by themselves than the panoramic spectacles in the principal amphitheaters or in the central chasm. In truth it is difficult to suggest anything which appeals more strongly to the sense of magnitude and at the same time satisfies it more completely than the downward look into one of these vast chambers of the second or third order. The Transept is perhaps the most perfect and pleasing of them all, but there are many others which fall short of it only in an immaterial degree. There are several fine ones in the Ottoman Amphitheater, and one especially which is even larger than the Transept and only a little less perfect in execution. The simplicity of the work, its symmetry, the definiteness of profile, the sustained character, arouse the mind at once, and the magnitude of it can be appreciated the more fully because the attention is not distracted by an endless number of objects, all of which are about equally impressive.

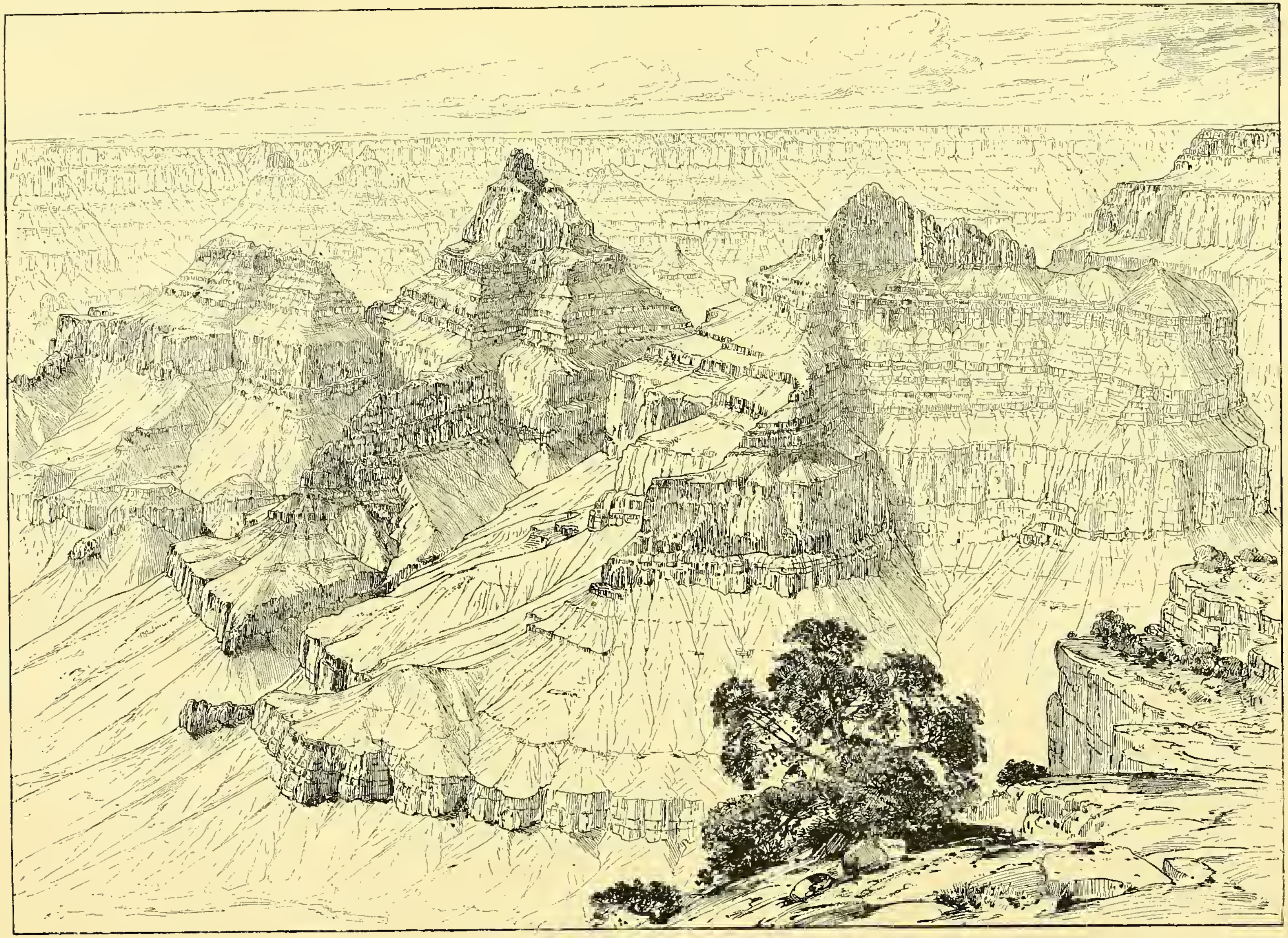
We can easily spend a whole day skirting the branches of the Ottoman Amphitheater without halting to contemplate anything in detail, but merely viewing them as we pass It is much smaller than the Tapeats or Shinumo, and a little smaller than the Hindoo or Bright Angel, but larger than several others of which no mention can here be made. The circuit of any one of these mighty recesses is a long, arduous day's journey by the shortest pos-

sible route, and around some of them it cannot be made in less than two, without excessive driving.

Passing around the head of the central and main branch of the amphitheater, we pause for a time to look into its depths and contemplate the grandeur of its walls. Moving onward seven or eight miles further towards the south, we at length reach the end of a promontory, from which we behold a panorama of the central chasm rivaling in grandeur that of Point Sublime. A part of it, however, is obscured by a vast cloister-butte in front of the cape and in close proximity to us. But though it hides what lies beyond, it is in itself so imposing that it compensates the loss. To the south and west the vista of the Grand Cañon stretches away in the fullest measure of its sublimity. The congregation of wonderful structures, countless and vast, the profound lateral chasms, the still lower but unseen depths of the central abyss that holds the river, and the overwhelming palisade of the southern wall, are much the same in their general effects as at Point Sublime; but the kaleidoscope is turned and the arrangement differs. We named this place Cape Royal. It may be considered as dividing with one other headland the distinction of being the end of the Kaibab.

Leaving the point, we make a detour to the eastward and descend into a large ravine and mount the platform beyond it. A ride of four or five miles brings us to the promontory, which we named Cape Final. Here we command a view of the head of the Grand Cañon. The scenery is in a large measure changed, not only in the arrangement of its parts but in its character. The portion of the panorama which includes the chasm is, in the main, similar to what we have seen from other commanding points, and so far is it from being diminished in grandeur that it may in some respects be regarded as the finest of all. But the chasm is only half the scene before us. To the eastward is spread out in full view the great expanse of the Marble Cañon platform, the Echo Cliffs beyond, and in the dim distance the Cretaceous mesas about the San Juan. To the southeastward is the far off mesa country around the Moquis villages sixty or seventy miles away, and to the southward fifty miles distant rise the grand volcanic piles of the San Francisco Mountains.

As we mount the parapet which looks down upon the cañon the eye



VISHNU'S TEMPLE.

is at once caught by an object which seems to surpass in beauty anything we have yet seen. It is a gigantic butte, so admirably designed and so exquisitely decorated that the sight of it must call forth an expression of wonder and delight from the most apathetic beholder. Its summit is more than 5,000 feet above the river. Mr. Holmes' picture will convey a much more accurate idea of it than any verbal description can possibly do. We named it VISHNU'S TEMPLE.

No point in the cañon presents so much matter of interest to the geologist as Cape Final. It is upon the crest of the East Kaibab monocline, and the local aspects of that displacement are remarkably clear. Looking southward across the river to the main wall, the strata are seen to possess a strong dip to the eastward, amounting to five or six degrees. This dip prevails through a distance of about six miles, and gradually increases the height of the southern wall by a corresponding amount. Or, conversely, the descent of the strata towards the east lowers the entire platform; for the same upper stratum everywhere in these parts forms the surface of the country. The monocline beyond the river gradually dies out. But on the north side of the river, and directly in front of us as we face the eastward, its dip is seen to be much greater, amounting to ten or twelve degrees, and as we follow it northward along the eastern Kaibab front we shall find the dip still increasing at a slow rate. But as it smooths out south of the river we may observe that the locus of displacement is transferred to the westward, for we can very plainly discern an abrupt upward turn in the flexure exposed in the cañon wall away to the westward. The dip for a short distance is as great as 25° or more, and after it has brought up all the beds to the westward five hundred feet the strata flex back to horizontality. This sharp flexure manifests itself far south of the river and away from it by a long hillside facing the east. As the eye follows it along its strike it perceives it growing in altitude and becoming more and more abrupt until it presents a tall cliff, which, ten miles south of the river, seems to be nearly or quite a thousand feet high. At that distance the East Kaibab monocline has wholly disappeared. This cliff, which undoubtedly has a fault at its base, has taken up the displacement and carried it on to the southward as far as the eye can follow it. To this extent we may, with perfect confi-

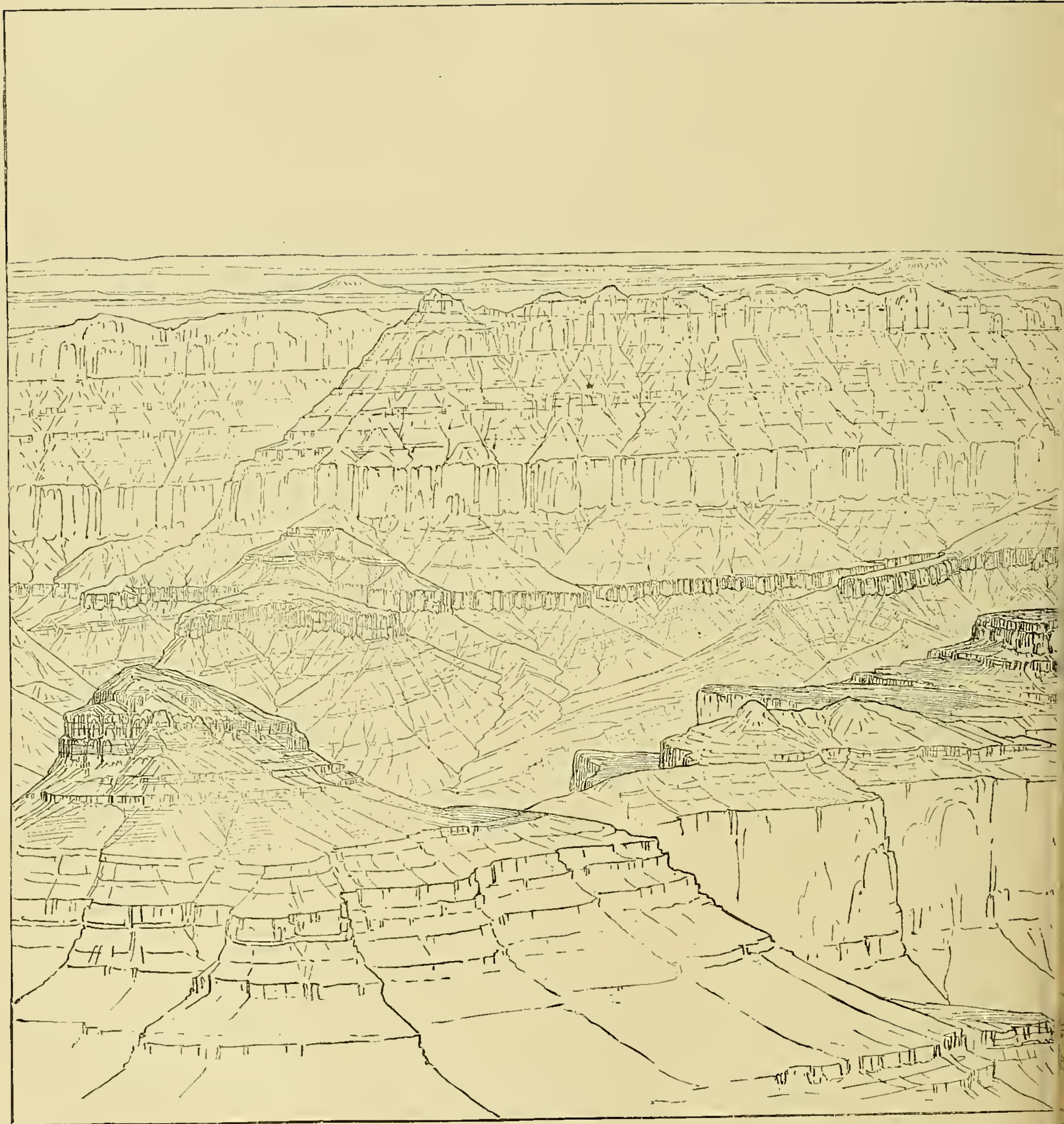
dence, predict the structure of the country many miles away, though no geologist has yet visited the locality.

To the east we can see the chasm of the Little Colorado as it approaches its junction with the Marble Cañon. Little of it is disclosed. An ordinary cañon seldom is seen until we are close upon its brink, and the cañon of the Little Colorado, though of very grand proportions, cannot be traced far, though we are more than 2,000 feet above the plain in which it is sunken. The place where it opens into the chasm of the Colorado is somewhat arbitrarily chosen as marking the lower end of the Marble Cañon and the head of the Grand Cañon. Here the Marble Cañon descends from the north, and, after passing the junction of the Little Colorado, the main chasm begins to pass, by a gradual transition, into the features of the Grand Cañon. The river sweeps around a long curve, changing its course to the westward, and enters the rising slope of the East Kaibab monocline. Through a distance of about ten miles from the junction the walls steadily rise more than two thousand feet higher, the abyss widens greatly, and the buttes, promontories, amphitheaters, and side gorges make their appearance.

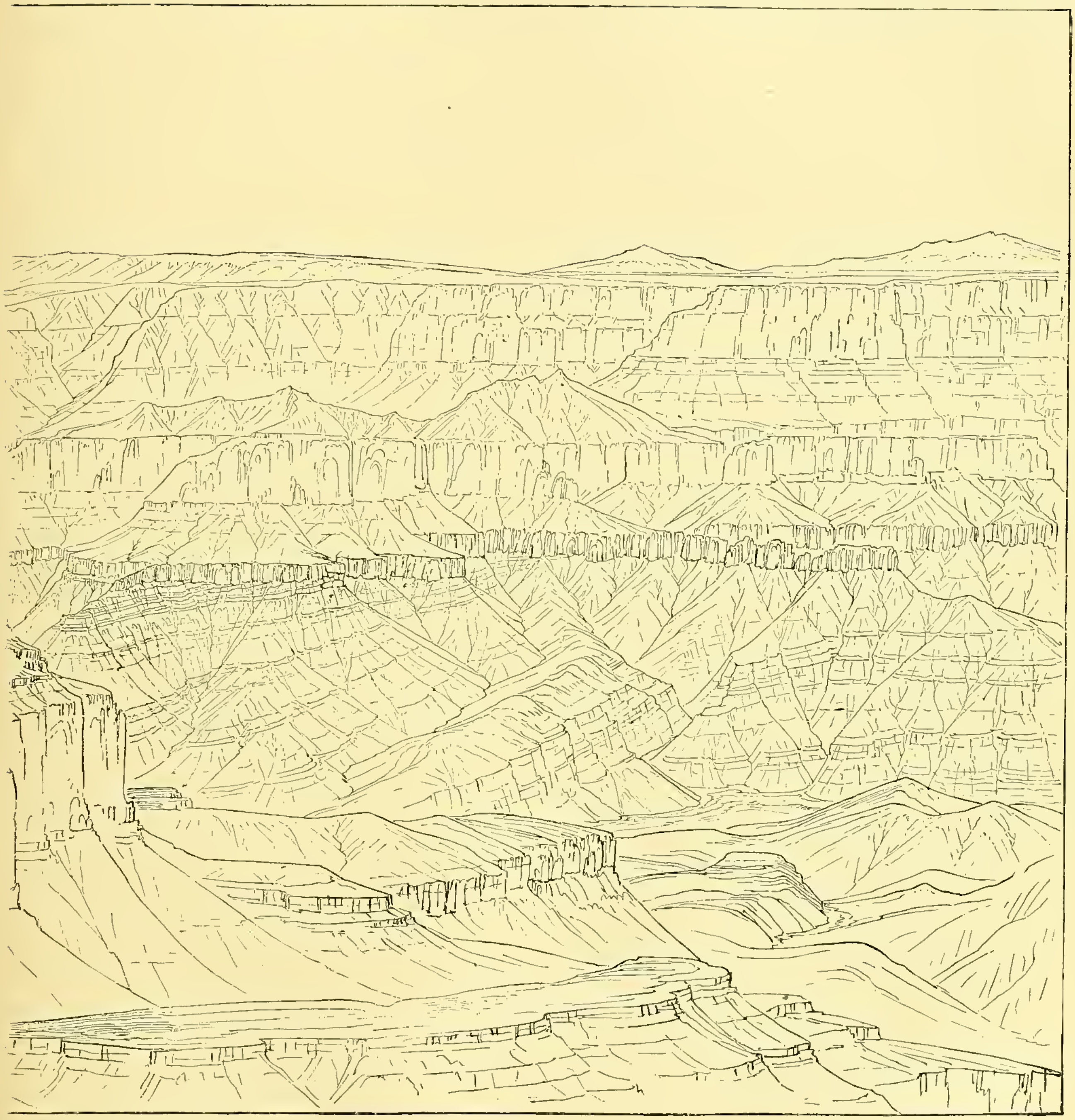
The havoc wrought by erosion upon the slope of the monocline is extreme. Here the chasm is wider than at any other place, and the terrible scoring by side gorges is at its maximum. Owing to the greatly inclined attitudes of the strata the resulting forms are no longer beautiful, but shapeless and grotesque. The whole Carboniferous system has been cut away from the monocline just east of the point, and the lower rocks are laid bare. And these lower rocks, from a purely stratigraphic point of view, are extremely interesting. To these we now turn our attention.

THE GREAT UNCONFORMITY.

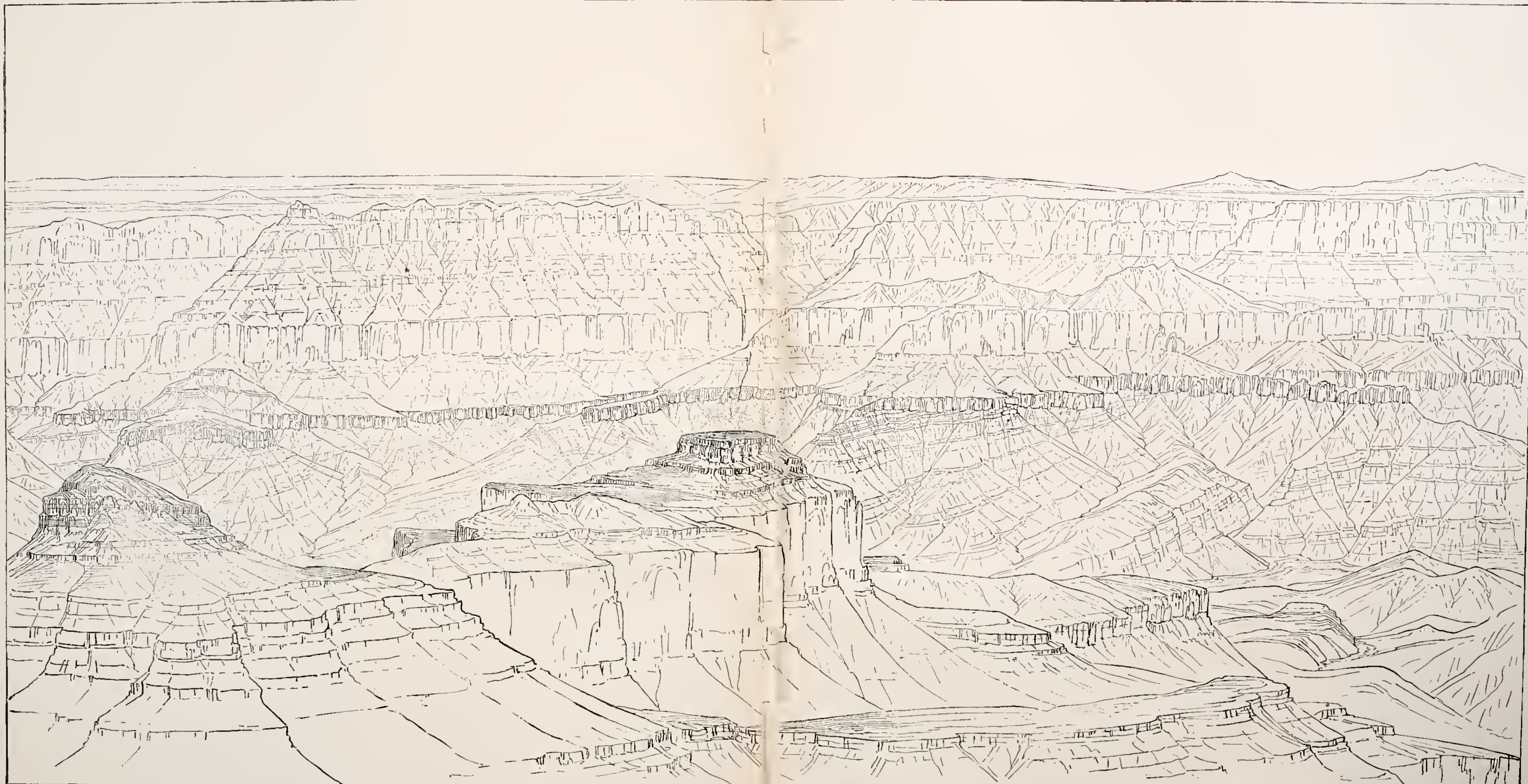
The Carboniferous series, 4,000 to 4,500 feet in thickness, is throughout this region perfectly conformable, so far as appearances go, from top to bottom. The lowest conformable group consists of a series of thinly bedded sandstones or quartzites, with a total thickness of about 180 to 200 feet. They have already been spoken of as exceedingly obdurate in charac-



THE GREAT UNCONFORMITY A



HEAD OF THE GRAND CANON.



THE GREAT UNCONFORMITY AT THE HEAD OF THE GRAND CANON.

ter, and wherever the river has cut through them their edges form a vertical ledge at the summit of the inner gorge. In the middle, and indeed through the greater portion of the Kaibab division, they rest immediately upon the Archæan schists. Wherever the opening of the inner gorge is disclosed, this ledge is a very conspicuous feature. At the head of the Grand Cañon it is also visible and as prominent as elsewhere, but this lower group here rests no longer upon the Archæan. An enormous mass of stratified rocks of older date has made its appearance, and the Archæan is far beneath them, and upon this older mass the lower Carboniferous quartzites are seen to repose unconformably. The dip of the Carboniferous system, which is still under the influence of the vanishing East Kaibab monocline, is about 5 or 6 degrees to the eastward. The dip of the strata beneath, though not quite in the same direction, is nearly so, and the amount of it is upon an average 14 to 15 degrees. As each stratum rises up to the plane of contact with the quartzites it is beveled off and disappears. Careful scrutiny discloses in the exposed edges an old fault, with a displacement of about 1,200 or 1,300 feet, cutting the lower strata, but not affecting the Carboniferous above; and the beds upon the lifted side (the throw or drop of the fault is upon its western side) are planed off to a continuous upper surface. Farther down the river is also disclosed an abrupt anticlinal fold in the series, which is also planed off to a uniform upper surface. For ten miles down stream this relation of the strata may be distinctly traced, showing a dip to the eastward which is visibly interrupted only by the fault and anticline just spoken of. The view of it is at length lost behind the buttes. The "granite" is nowhere seen, but we know that it comes to the daylight only a mile or two beyond the point where the inner gorge winds out of sight. The thickness of this mass must be very great. As we follow down the river every mile of progress must bring up about a thousand feet of lower and lower beds, and the cumulative effects of this rise appear to be subject to subtraction only at the fault and anticline just spoken of. Altogether there must be at least 6,000 feet of them, and Professor Powell, who saw them in his descent of the river, estimates the total thickness at not far from 10,000 feet. Unless there are more faults or anticlines which cannot be seen from Cape Final, his estimate is apparently justified.

The age of this series is probably Silurian. Devonian beds may also be found in its upper part, but all that we can say about their age now is that they are pre-Carboniferous. Lithologically, they appear at a distance very much like the rainbow beds at the base of the Trias and summit of the Permian in the Valley of the Virgen. The bedding is very uniform and regular. The colors are chocolate, purple, lavender, and magenta, of many tones and shades. If it were not for this powerful coloring, which discloses every band and layer with emphasis, and each with a habit peculiar to itself, we could not venture to assert so much about them as we have done. For we have been reading geology five to ten miles away from our rocks. But what are miles in this Brobdingnagian country! These things seem to lie at our very feet.

Just where the comparatively narrow gorge of the Marble Cañon expands well out into the much ampler width of the Grand Cañon, we perceive among the higher beds of this ancient series some layers which we do not hesitate to pronounce volcanic rocks—basalts or diabases. They are coal black, and contrast finely with the rich colors all around them. They are interbedded with the upper Silurian (?) strata, but whether they are intrusive sheets or contemporaneous *coulées*, outpoured while the rocks were accumulating, we cannot say. The very dykes through which the lava came up are visible. Powell saw them on his boat journey down the river, but did not have an opportunity to investigate the many interesting questions which they suggest.

Throughout the remainder of the cañon, although the pre-Carboniferous rocks are laid open for more than half the distance, there is no such exposure of early Paleozoic strata. Wherever the lower quartzites are cut through they are usually found resting upon the schists. In several places, however, remnants which correspond to the base of this Silurian series are disclosed between the quartzites and the schists, but the mass seldom exceeds 200 feet, and, perhaps, never reaches a thickness of 400 feet. A few Primordial trilobites have been found in these remnants. The meaning of this great unconformity obviously is that after a vast body of early Paleozoic strata had been laid down they were distorted by differential vertical movements, were flexed and faulted, and were elevated above the sea.

They were then enormously eroded. Across the belt of country bounded on the east by the longitude of Cape Final and extending as far west as the lower end of the Grand Cañon, a rectilinear distance of nearly 110 miles, and, for aught we know, indefinitely further westward, nearly the whole mass of these strata was denuded. A few, and perhaps many, small remnants at the base of the series were preserved, but over most of the area the Archæan schists were laid bare and suffered erosion. Still later the region was again submerged. Over the rugged country thus ravaged 4,500 feet of Carboniferous beds and 9,000 to 10,000 feet of Mesozoic beds and, perhaps, 1,000 to 1,200 feet of lower Eocene (lacustrine) were deposited.

It is with extreme regret that I am obliged to confess that there seemed to be no way to obtain access to these beds for the purpose of studying them in detail. At present they can be reached only by boat through the Marble Cañon, and the locality can be left only by descending the Colorado as far as the Kanab Cañon. There seemed to be no possible way of getting down the gigantic walls which inclose this valley of Rasselas. The Red Wall limestone is apparently everywhere a vertical escarpment a thousand feet high, except at some of the long spurs, where it breaks into needles and minarets, which look almost as hopeless.

Point Final is doubtless the most interesting spot on the Kaibab. In pure grandeur it is about the same as Point Sublime, though less typical of the cañon. The two localities differ much in the characteristics of the scenery. The former gives us, in addition to cañon scenery, a vast panoramic view of the distant regions in the heart of the Plateau Province, where nothing is distinctly visible, but where the imagination perceives more than the eye. There is a dim vision of cliff upon cliff and throngs of richly-carved buttes, where the fancy runs riot, while the sober sense tells us that it is a *mauvaise terre*—a land of marvels indeed, but also a land of terrors and desolation.

Leaving Point Final we return northward, keeping now near the eastern front of the Kaibab. Here the great feature is the KWAGUNT VALLEY, an excavation which is quite analogous to the ordinary amphitheaters of the first order, which we have already seen. It lies along the southern portion of the eastern base of the Kaibab, reaching up to the northward about 15

miles from the river. Several large amphitheaters of the second and third orders open into it, scooped out of the great monocline, and these are always very fine and imposing. North of the Kwagunt is another one, cut out of the East Kaibab monocline, and it opens into the lower portion of the Marble Cañon. It compares favorably with the others. Further northward several large recesses are excavated in the eastern flank of the Plateau, but they all debouch upon the Marble Cañon platform. These will be alluded to hereafter.

CHAPTER X.

THE STRUCTURE AND DRAINAGE SYSTEM OF THE KAIBAB.

The principal displacements and general form of the plateau.—The West Kaibab fault.—The East Kaibab monocline.—Relations of these displacements to each other and their continuations south of the river.—The summit strata of the plateau.—Age of the uplifting of the mass.—The relations of the Colorado River to the plateau as bearing upon the question of age.—Ancient river channels.—House Rock Valley.—The moist climate of the Miocene and arid climate of the Pliocene.—Lower altitudes in former periods.—De Motte Park and its significance.—Ancient river channel on the summit.—The ravines of the Kaibab.—Their conformity to the structural slopes.—Exceptional character of the Park drainage.—The origin of the ravines conjectured to have been in the glacial period, which was rainy here without ice.—Considerations upon the amphitheaters excavated in the East Kaibab monocline.—The inferences drawn from them as to the age of the plateau.

The Kaibab is a platform uplifted between two displacements. Upon its eastern side is a great monocline where the Carboniferous strata as we come from the east suddenly flex upwards and then flex back to horizontality upon its summit. Crossing the platform from east to west, and reaching its western margin, we perceive the same strata dropping suddenly by a great fault, and their continuation towards the west forms the Kanab Plateau The displacement upon the eastern flank is the East Kaibab monocline; the one upon the western flank is the West Kaibab fault. Towards the north the two slowly converge and at last meet at a very acute angle in the vicinity of the little village of Paria and at the base of the Vermilion Cliffs. The Kaibab platform between them, therefore, terminates in a cusp. Since the two dislocations throw in opposite directions, the result of their union is a single flexure having an amount of displacement equal to the difference of the two at the point of junction; and this flexure continues northward through the terraces on the eastern side of the Paria Amphitheater and extends into the High Plateaus

The courses of these two displacements southward from Paria village are not straight lines, but curves convex towards the west. Their relations

to each other may be conceived by recalling the image of the crescent moon. The outer curve or "limb" might answer to the form of the West Kaibab fault; the inner curve or "terminator" to the form of the East Kaibab flexure; the included horn to the form of the northern portion of the plateau. But the southern portion has no such analogy.

For many miles south of the Paria these dislocations preserve great simplicity of character, but as they approach the Colorado River they undergo changes and gradually die out. The West Kaibab fault is the first to resolve. For about 40 miles it is a simple fault, gradually increasing in the amount of its shear from 500 to about 1,800 feet. At this point the thrown platform of the Kanab Plateau on the west begins to rise quite notably, and slowly brings up the edges of the thrown strata towards the level of the Kaibab summit, thus diminishing the fault. About ten miles further on a new parallel fault begins, throwing also to the west, and the total shear is distributed between the original fault and its neighbor.

Further on a third parallel fault appears, and the displacement is distributed among the three, which thus form a series of "step-faults" Meantime, the Kanab platform has been rapidly rising southwardly, while the Kaibab has increased its altitude only a very little; and that abrupt escarpment which separated the northern part of the Kaibab from the Kanab has gradually faded out. But it has not wholly vanished, though it has become profoundly modified. In the north a great wall, more than a thousand feet high, separates the two; further southward the wall diminishes in height; at length the single wall becomes two steps; further on it becomes three steps, the heights of which continually decrease; and at last it becomes an inclined plane, sloping about $1\frac{1}{2}°$ to $2°$ towards the west, and all the faults have vanished or have been replaced by new dislocations trivial in amount.

The East Kaibab displacement undergoes another set of modifications. For more than thirty miles south of Paria it is a simple and abrupt mono cline. Near the head of House Rock Valley the monocline divides into two steps. This is common enough in faults, but that the same sort of phenomenon should be presented by a simple monoclinal flexure is very significant and adds another illustration of the complete homology between faults and monoclines. The duplex character of the displacement

is preserved for a distance of about thirty miles further south, and then it reverts to its simple and single form. Thence onward the fold gradually smooths out, becoming less inclined but much wider. The amount of displacement, however, does not at first diminish very rapidly, for though the inclination of the strata becomes rapidly less, it also becomes wider; the hill is less steep but it is longer. At length as we approach the Colorado the displacement dwindles more rapidly, and a few miles south of the river it gradually vanishes. But in the meantime a new displacement parallel to it has made its appearance further to the west, and this is well worth studying, for the indications are that it is a reäppearance of the West Kaibab fault, greatly changed in its course or trend and its displacement reversed. Reverting here for a moment to the West Kaibab fault, we find it leaving the Paria neighborhood with a southwesterly course, gradually changing to the south and then southeast. As it nears the Grand Cañon its throw greatly diminishes, and I believe it vanishes entirely about four miles north of the brink. At all events, nothing has been seen of it near the brink. But looking across the chasm from the north side a flexure is seen in the great wall upon the southern side, truly monoclinal in form, with a displacement of about 450 feet. It is in the line of continuation of the vanishing main branch of the West Kaibab fault and its throw is reversed. Its eastern side is dropped, while the proper West Kaibab fault drops its western side. This reversal of throw is a feature not uncommon in the long faults of the High Plateaus as we follow them in their immense longitudinal extensions. Thus, by a very curious, though perfectly intelligible process, the displacement which constitutes the western side of the plateau has gotten upon the eastern side. South of the chasm it continues with a southeasterly course, becoming a true fault and increasing in the amount of shearing for nearly twenty miles. Its further extension and method of resolution is not at present known.

All of the displacements of the Kaibab thus far observed are of very simple character, being true faults or monoclines with comparatively little complication or subordinate fracture at the fault planes. We may note, however, in the West Kaibab fault and in the parallel step faults into which it divides, that feature which is so frequently observed in many of the great

displacements of the district—viz., the turning down of the edges of the thrown beds in the vicinity of the fault-plane. This is revealed very strikingly in Stewart's Cañon at the elbow where it turns abruptly to the west to join Kanab Cañon. It is also seen upon the east side of the outlying mass called Powell's Plateau, which is separated from the Kaibab by a gorge about 1,200 feet deep. One of the steps of the fault cuts through this gorge, and the edges of the beds upon the west side are seen to be turned down. The same feature is observed in the extension of this fault southward into the mazes of the cañon, and it is revealed in the great buttes and in the plinth walls of the cloisters, which fill the ample expanse of the chasm.

The plateau mass between its bounding displacements is very nearly horizontal. Not quite so, however. The strata are just perceptibly arched in a broad anticlinal swell. The dip, however, even near the edges, where it is a maximum, does not exceed 2°, until (upon the eastern side) the influence of the monocline is felt, and then the strata suddenly turn down at a great angle. It was for a time suspected that the basin of De Motte Park was the result of the dropping of a wedge-like mass between two faults, but more careful study renders it certain that it is an ancient valley of erosion.

The continuation of the Kaibab Plateau upon the southern side of the Grand Cañon has no definition except upon the east. The fault which has already been alluded to gives rise to a slope which gradually becomes a high and abrupt cliff facing northeast and forming the eastern boundary of the plateau. Westward the platform declines by a very gentle slope, and grades into the general expanse of the Colorado Plateau without any line of demarkation.

The altitude of the Kaibab at the highest point is about 9,300 feet above the sea. From De Motte Park northward it slowly declines. The altitude of the southern portion above the Paria or Marble Cañon platform lying eastward is from 2,700 to 3,600 feet. Its altitude above the Kanab platform on the west is very variable, but ranges from 1,000 to 2,300 feet, according to the places in close proximity which are compared.

Neglecting the minor inequalities, the general surface of the plateau

conforms very closely to the upper surface of the Aubrey limestones. The principal inequalities have their origin in the unequal amounts of uplifting which have prevailed in a platform of beds that once were horizontal. In other words, they are almost wholly structural, and not imposed upon the mass by unequal erosion.

The principal points in the history of the evolution of the Kaibab may be discerned by a comparative study of the drainage and displacements. The argument here adopted is not a new one, but it is to be carried to an unprecedented extent. Its validity can only be judged by the result. In other countries—in regions where the geological data are more obscure—its application would be very doubtful and perhaps impossible; but here the data are exceptionally plain and definite, and enable us to co-ordinate the facts and draw conclusions with a high degree of confidence.

It has repeatedly been remarked that the principal structural features of the Grand Cañon district are comparatively recent in their origin, probably going back no further than the early Pliocene, while the principal drainage channels are as old as the epoch at which the lacustrine period terminated. We infer that the establishment of the drainage is older than the structural features, because if we suppose otherwise, then the drainage would have been very differently distributed from that which now exists. For example, let us suppose that the Grand Cañon were filled up evenly with the summit of the cliffs which overlook it. The Colorado River being thus dammed, a large lake would be formed. When the inflowing waters had filled this lake the outlet would be at the northern extremity of the Kaibab near Paria. Here is the lowest barrier which would keep the water from the ocean. Supposing Kanab Cañon to be also filled up, the course of the waters would be to the westward, and they would finally pour over the Hurricane Ledge at a point near that where the Virgen crosses it. This is the course which the Colorado would take if the present structural configuration were to determine it anew. The inevitable inference is that the course of the river could not have been determined by the existing structure, and must have been fixed by a configuration older than the present one. The mind therefore recurs to the earliest period, far back in the Eocene, when the waters of the lake receded and left a river running in the deepest

part of its basin. The gradual elevation of the entire region was the cause of the gradual desiccation of the lake, and the channel through which its waters escaped, once established, could not have been changed without leaving some indication of the process which could have effected such a change. A powerful river traversing a region which is undergoing a great amount of uplifting must ever sink its channel deeper and deeper in the strata, and its position must be growing more and more immutable.

The present position of the Grand and Marble cañons, therefore, is the locus of the deepest part of the Eocene lake. This conclusion is reached by another course of reasoning. If we restore the strata to the condition of horizontality, if we replace in imagination the bodies of Mesozoic and lower Eocene strata which have been denuded, we shall be led to infer the existence of a vast and nearly level platform coextensive with the great areas now draining into those cañons. But if we suppose the strata to have thickened as they approached their shore-lines we should also infer the existence of two converging slopes, one descending from the northwest, the other from the southwest, and meeting in a line very near and perhaps exactly in the position of these cañons. Thus, the law of persistence of rivers and the analysis of the vertical movements of the region bring us to the same conclusion. The study of the tributaries also tends to the same result. The Kanab and Paria rivers are plainly independent of the inequalities of uplifting, and must be older than the displacements.

These tributaries shed further light upon the earliest condition of the Kaibab area. The Kanab and Paria are apparently as old as the Colorado, and had their origin in the same train of events. Each represents a subordinate and lateral drainage basin, and between the two lay a certain extent of higher ground. Just at the base of the East Kaibab flexure is House Rock Valley, which once held a river which has long since vanished, though leaving well-marked traces of its former action. This intermediate valley divides the interval between the Kanab and Paria basins into two masses; the western is the Kaibab, the eastern is the Paria, plateau. None of the great displacements which traverse these masses had any existence at that remote epoch.

The earliest condition of the Kaibab, then, is inferred to have been

merely a slight elevation between the Kanab and House Rock valleys. The subsequent events which have made it what it is may be discerned in studying the combined effects of erosion and unequal uplifting.

The great erosion which has removed so vast a body of strata from this region is believed to have been chiefly the work of Eocene and Miocene time. The general uplifting, which has prevailed throughout the entire extent of the West, had its inception in Eocene time. This is indicated by the gradual but somewhat rapid transition of the older areas from a marine and estuarine condition to the lacustrine, by the progressive shrinkage of the great Eocene lakes and the cessation of widely extended deposition of strata. The lake basins, becoming dry, were at once attacked by the degrading forces, and as they rose higher the efficiency of the degrading forces augmented. Such indications as we now possess as to the climatal condition of the region in those periods are somewhat meager, but are still sufficient to warrant the belief that the climate was moist and subtropical. Here and there in the surrounding regions we find remnants of temporary lakes, some of them of great size, which disclose in their strata abundant forms of vegetable and animal life, among which are remains of mammalia of great size, with numerous species. These fossils and their associations all imply a great exuberance of animal and vegetable life which is hardly possible without a moist climate—a climate certainly much moister than that now prevailing there, though not necessarily extreme in this respect. The palms, which constituted some of the most abundant vegetable forms, also show that it was much warmer than at present. Thus a region undergoing progressive elevation with a moist warm climate may be inferred to have wasted away rapidly under the action of degrading forces.

There are as yet no known facts which enable us to mark the periods of Tertiary time and co-ordinate them with those which have been established in other regions. Yet there are indications which point to the conclusion that after the vast body of Mesozoic beds had been in great part swept away, the denuding forces for a time abated their destructive energy, and indirectly we may infer that this diminution of the degrading forces had its epoch not far from the close of the Miocene. The great denudation up to that epoch had been going on vigorously throughout the whole of

the Miocene age and through at least two-thirds of the Eocene, and though we may not reckon this period in terms of centuries we cannot doubt that it was a vast one, and sufficient, under favorable conditions, for an enormous amount of waste. The work of removing nearly 10,000 feet of strata from a great area is a formidable thing to contemplate, but under the given conditions the time-factor will no doubt be regarded as being commensurate. What aspect the country presented during this great stretch of time we have no means of judging. All records of even the broader details have vanished with the strata. We only infer that not far from the close of the Miocene the great mass of Mesozoic beds had been in chief part denuded; that the resulting platform of the Grand Cañon district was at a much lower level than at present, and probably not very far above the sea-level. The cañon of the Colorado either did not exist at all at that time or was at most only just begun.

At this epoch the climate gradually became more and more arid. Although the evidence of this is not found in the district itself, it appears conclusively in the regions adjoining it. It is a remarkable fact that the Pliocene lake-basins, both north and south of the Grand Cañon district, exhibit saline deposits, while the earlier lake beds show nothing of the kind. A saline lake-deposit means an arid climate—small feeble streams flowing into an inclosed basin, which they cannot fill to overflowing, because evaporation is so rapid that it keeps pace with the influx. And as the adjoining regions were arid, so also we conclude was the Grand Cañon district. This inference is further sustained by the fact that those traces of Pliocene erosion which are here and there preserved have the characteristics which belong to the sculptural forms of an arid region. These are ancient cañons with abrupt walls in the more adamantine strata which have survived the ravage of later periods. Thus, through the Pliocene the conditions were unfavorable to a very rapid rate of degradation. During the glacial period, however, this rate must have been vastly greater; but, if we are to attach any value to current estimates of the relative duration of geological periods, this episode was comparatively brief. At its close the climate lapsed back to its former aridity.

It will now become apparent why we infer that at the commencement of the Pliocene by far the greatest part of that great denudation which swept away the Mesozoic beds had been accomplished. Before that epoch (early Pliocene) a moist climate prevailed for an immense stretch of geological time—the whole of the Miocene and most of the Eocene—and the region was rising. Since that epoch an arid climate has for the most part prevailed, and the period of its prevalence has been much shorter. We cannot doubt that the longer duration of a more efficient cause must have produced a far greater erosion than the much shorter duration of a less efficient cause. The exact ratio of the results produced in the two durations, respectively, cannot indeed be determined; but we cannot well avoid the conclusion that the disparity was very great.

The reason for believing that at the beginning of Pliocene time the district was at a much lower level than at present is equally forcible. The East Kaibab monocline and the Grand Wash fault, which bound the Grand Cañon district, cannot have originated at an older epoch than the one in question. They mark the difference between the amount of final elevation of the district and of the regions on either side of it. It is true that a fault may indicate either an absolute uplift on one side or a downthrow on the other. Which interpretation shall in any given case be adopted turns upon collateral facts. In the present instance there is no reason for hesitation. The Grand Cañon district is obviously an uplift between the two abovementioned displacements. The other view raises insuperable difficulties at once. It would require us to believe that the whole country extending indefinitely east of the Kaibab had once been several thousand feet higher than at present, and subsequently subsided without leaving any evidence of such an event; and the same inference would be applicable to the region extending from the Grand Wash indefinitely westward. Such arbitrary and needless assumptions are not worthy of consideration. The only rational conclusion left us is that the Grand Cañon platform has been raised since the Miocene by an unknown amount, though a part of that amount is directly indicated in the displacements now observable on either side of it. The reduction of these displacements to their original condition would diminish the altitude of any given stratum from 2,500 to 3,500 feet upon the

eastern side of the district, and more than 6,000 feet upon the western side. And if, as is most probable, there has been a general upward movement during Pliocene time affecting all of that portion of the continent the change of altitude has been correspondingly greater. The amount of this more general upheaval can be deduced for the whole of Tertiary and Quaternary time, but how much was accomplished before the advent of the Pliocene, and how much since, it is impossible to say.

It is necessary to remark here, that the reference of this divisional epoch to the commencement of Pliocene time ought to be considered with some qualifications. It should be borne in mind that a strict correlation of geological periods is here impossible. We have within the district no Pliocene beds and no Pliocene fossils. Nevertheless, events point to that epoch as the approximate one, when the present order of things took their forms and relations. The error cannot be great.

With the Pliocene, as thus understood, the Kaibab began to have a distinct existence. Probably at this time the great East Kaibab monocline began to develop itself. It is older than the Hurricane fault, and older than either of the displacements which occur between it and the Grand Wash. The reasons for assigning an early Pliocene date for the East Kaibab monocline may be found in a comparison of the drainage channels. The problem is a charming one, carrying the requisite data for a satisfactory conclusion, but it is also complex and difficult to present clearly to a reader who has not thoroughly traversed the ground and made himself familiar with the surface topography of the plateau. Nevertheless, the attempt must be made, and if it fails to convey a clear idea of the facts presented, and therefore fails to convey a clear conception of the interpretation of them, it must be attributed to the difficulty which always attends the effort to draw a mental picture of a distant region from a merely graphic description.

Along the greater part of the length of the Kaibab, and keeping very near to the median or axial line of the summit of the plateau, there is a long and comparatively narrow valley. The depth of this valley is from 200 to 400 feet, and its width is from one to two miles. It is seen in the northern part of the summit, where it is rather shallower than in the middle portion.

De Motte Park is a portion of the same depression. Farther north it diverges from this median or axial position, and trends off slightly toward the southwest, ending at last upon the brink of the great chasm. In several places the valley bottom, as we follow it from north to south, reverses its grade. But in general there is a slight upward slope for more than forty miles, until we reach the "Sylvan Gate," at the foot of the larger De Motte Park. Passing through the gate the grade of the valley descends toward the south. When the geologists first visited the plateau they were considerably perplexed by this long valley or chain of valleys. They observed that from the summits which overlook them on either side nearly all the drainage channels flowed away from it, and very few flowed into it. Upon these summits the numberless ravines took their rise—those upon the western side flowing away from it like rays in every direction west of the meridian, those upon the eastern side also flowing away from it, but not in the same manner. The origin of these summit ravines, their courses, and their distribution, were easily explained, but the origin of the median chain of parks which separated the eastern drainage-plexus from the western was a mystery. Powell and Gilbert were at first inclined to suspect that a long, narrow wedge on the summit of the plateau had dropped between two faults, but no faults could be discerned, and they abandoned the supposition. During the last season a thorough survey of the drainage system was made, and I think the mystery may now be cleared up. In the first place, the existence of the supposed faults was positively disproven by the discovery of the cross-bedded sandstone of the Aubrey group just where it ought to be in case no faults exist, or where it could not be if the faults did exist. In the second place, the chain of valleys is the locus of an ancient river which once flowed from the north and emptied into the Colorado. This river was far more ancient than any of the other drainage channels now scoring the surface of the Kaibab, which are all of comparatively recent origin. What antiquity should be assigned to it may not be altogether established, but by far the most probable supposition is that it is as old as the Colorado itself and its tributaries, the Kanab, Paria, and Little Colorado. We are not concerned, however, to find an origin so remote as these, but only to find that it antedates the Pliocene. That it belongs to the system of drainage which pre-

vailed when the structural conformation of the country was very different from the present one is self-evident. The course of its valley for the most part is against the structural and topographical slopes, and therefore the river was older than those slopes. That is to say, when this valley carried a living stream, the Kaibab as a distinct plateau had no existence.

Two causes may be readily discerned which destroyed this river. The first was the arid climate of the Pliocene, which greatly reduced its water supply. The second was the peculiar distribution of the uplifting, which, being greater along the lower courses of the river than along the upper reaches, had a tendency to reverse the slope of its channel. But Kanab Creek has persisted to the present day in spite of similar adverse conditions, and has maintained itself by cutting down its channel as fast as the country rose. But in the extinct river of the Kaibab a still more adverse arrangement of the uplifting destroyed it. For the uplifting was of such a distribution that the river was left upon the axis of a water-shed instead of in a broad drainage-basin, and was thus deprived of tributaries and feeders.

At what epoch was this river destroyed? It perished at the epoch when the Colorado was running in the cross-bedded sandstone of the Upper Aubrey group, 5,000 feet above its present bed! If we follow its channel from the park toward the confluence with the Colorado, we find it sinking to the surface of this adamantine stratum, and a few yards into it. At last the valley ends suddenly in the mighty wall of the chasm, and from its trough we look down upon the great river a mile below and three or four miles beyond us. When the valley sustained a living stream it must have done just what the other tributaries did—cut down its bed in harmony with the Colorado itself. When its waters ceased to flow the valley ceased to deepen. It has never carried a stream since, and has never grown materially deeper. Its present floor marks the horizon upon which its waters ceased to run, and where the Colorado left it and continued to sink deeper through the succeeding ages. But the cross-bedded sandstone is within 600 or 700 feet of the summit of the cañon wall, and when the Colorado was running over it the work of excavating the present Grand Cañon had just begun. Already the reasons have been given for referring this epoch to the beginning of the Pliocene.

Thus, the destruction of this ancient tributary, itself a member of the early Tertiary river system, is associated with the movement which uplifted the Kaibab, and with the great monocline by which that movement is indicated and in part measured, and the epoch of these events relatively to the age of the river is also determined. The validity of this reasoning is attested by a great and complex array of facts, and it brings into wonderful harmony and order a mass of observations which otherwise are inexplicable. At the risk of becoming prolix, I venture to cite some examples of facts which give independent support to the conclusions just drawn.

The whole surface of the Kaibab is covered with a maze of ravines, of which a description has already been given in Chapter VII. These are delineated with great care by Mr. Bodfish in Atlas sheets 11 to 14 inclusive. Those which are found upon the western side of the De Motte Park radiate away from it in all directions between northwest and south-southwest But not one of them flows into the park. On the eastern side there are two distinct groups of drainage channels separated by a subordinate watershed, or divide, which extends from the summit overlooking De Motte Park eastward to the brink of the plateau. The northern plexus flows eastward and northeastward; the southern plexus flows southward and southwestward. The former passes down into vast gorges and amphitheaters cut into the great monocline and debouches upon the Marble Cañon platform; the latter descends into the amphitheaters of the Grand Cañon. The origin of these innumerable ravines is apparent at a glance. With a very few exceptions, they all follow the structural and general topographical slopes of the plateau. If they could all be filled up again and the surface of the country smoothed off evenly with the surface of the upper Aubrey limestone and then left to the action of copious rains, the ravines would form anew and the new ones would have nearly the same general arrangement, the same general courses, the same general aspect, as those which now exist. Some slight structural changes may have occurred since the present channels were formed, and these might produce differences in the supposed new arrangement, but they would be of small amount. What better evidence than this could there be that these ravines were laid out and cut *after* the

plateau had received its present structure, and that they were determined by it?

But the great park valley is in complete contrast to all this. Throughout its northern portions its course is in direct opposition to the structural slopes and throughout its southern portion it lies obliquely across them. Everywhere it is independent of them. What better evidence could there be that it was laid out *before* the plateau had received its present structure and that it was not determined by it? Its greater antiquity than that of the other valleys is attested by many evidences. Its aspect is strikingly different. It is very wide while the others are very narrow. The widening of valleys is a familiar phenomenon in this region. Those cañons which are now dry are everywhere widening without becoming deeper.

The other ravines are not apparently very old. My conjecture is that they had their origin in the glacial period. In this region that period was not properly glacial, but rainy. Not a trace of glacial action is discoverable upon the Kaibab. But the evidence of a much moister climate than the present one in southern Utah and Arizona is conclusive. The existence of such lakes as Bonneville and Lahontan during the glacial period admits of no other interpretation. The ravines of the Kaibab were unquestionably scoured out by running water. At the present time such action has entirely ceased, and it is probable that the ravines are very slowly filling up with soil and sand, and it is certain that they are not deepening.* I can frame no conjecture so satisfactory as that which supposes that during the glacial period the rainfall was sufficient to sustain living streams in these ravines and that they were then carved by running water. Prior to the glacial period the climate was arid like the present. In a country like this, where the strata are horizontal or dip but slightly, the effect of an arid climate upon the drainage is to obliterate the greater part of the channels and to increase the area of the individual drainage basins. A few

* In Chapter VII I have adverted to the fact, that although the rainfall of the Kaibab is very considerable—perhaps 25 or 30 inches per annum—there is not a living stream upon its surface. In an ordinary region such a precipitation would sustain many creeks and brooks. But here the water sinks at once into the earth and reappears in the profounder depths of the great amphitheaters and gorges which open into the Grand Cañon. The case is a very striking and suggestive one and seems to be analogous to the limestone country of Kentucky. The existence of subterranean streams beneath the Kaibab is apparently well attested. They emerge usually from galleries situated at the base of the Red Wall group and sometimes still lower.

channels are kept open; having large basins, which furnish water enough, even though it be in the form of intermittent supply, to maintain a cañon and corrade its bed. This is seen to-day all over the Kanab and Uinkaret Plateaus. During the Pliocene the same obliterating process probably prevailed upon the Kaibab.

If, then, the great number of drainage channels upon the plateau took their origin at the beginning of the glacial period, the park valley must be much older. But we could not well suppose that it originated during the arid period of the Pliocene in a climate which dries up rivers instead of creating them, and we must therefore go farther back. It seems plain that the river was running during the periods of the great denudation—during the Eocene and Miocene, or certainly during the late Miocene—and that it became extinct when this denudation had been nearly or quite accomplished. The reasons for assigning this epoch to the beginning of the Pliocene or thereabout have already been given. Thus we arrive at the same conclusion as before. In reaching it we may note by the way the satisfactory manner in which our first perplexity is removed concerning the relation—or, rather, want of relation—between the park valley and the other drainage channels. We could at first discover no solution of their origin which would apply to both. But when the topographical details had been mastered and grouped in the mind the true explanation seemed to stand forth clearly and unmistakably. And when the facts of the drainage were placed in relation with those of upheaval and again with those of climate, the whole took form and coherence and disclosed a history, the verity of which needs no better support than its self-consistency.

The conclusions drawn from the study of the Uinkaret now appear to be confirmed by the study of the Kaibab. We find certain facts common to both plateaus, and their relations and logical grouping are apparently identical. Both localities tell the same consistent story. Each, however, possesses features peculiar to itself. But the peculiarities in no respect conflict; on the contrary, they contribute separate quotas of strong circumstantial evidence of the verity of the main conclusions.

Before closing this part of the subject it may be well to advert to the great amphitheaters excavated in the monocline on the east side of the

Kaibab. These magnificent gorges compare well in many respects with those which open into the Grand Cañon. They have less depth, but are very nearly or even quite as wide. Those which are near the southern end of the plateau are in all respects the rivals of those which open into the great chasm, being of about the same depth and amplitude. But as we proceed northward, and away from the river, their depth suddenly diminishes. The reason is obvious: they open upon the Marble Cañon platform, which is about 3,000 feet above the river, and no mountain gorge can be excavated lower than, or even as low as, the level upon which it debouches. Both series, however, have been excavated nearly to the lowest possible depths, and their relative ages can be judged better by the widths than by the depths. Allowance must also be made for differences in the conditions which favor or retard this kind of erosion. All things considered, a comparison of the two series of amphitheaters leads to the impression that the times required to excavate them were not very unequal. Much uncertainty of course must attach to such an inference, but it may be said that no reason appears at present for assigning a longer period to one series than to the other. This would lead us to assign to the monocline the same age as that of the Grand Cañon—a conclusion identical with that already drawn. Although this argument, considered by itself, is so precarious that it could not alone justify so important a conclusion, yet when taken in connection with the whole mass of concordant facts it adds something to the volume of cumulative evidence upon which the conclusion is based.

CHAPTER XI.

THE PARIA PLATEAU AND MARBLE CAÑON PLATFORM.

Triassic strata of the Paria Plateau.—Recession of cliffs and the effect of faulting upon its rate.—Causes of retardation in the recession.—Drainage system of the surface of the plateau.—Valley of the Paria River.—House Rock Valley.—The smaller drainage channels attributed to the moist climate of the glacial period.—The Marble Cañon platform.—The Marble Cañon.—The Little Colorado and its relations to the region through which it runs.—The Echo Cliff monocline.

The platform between the Echo Cliffs and the Kaibab possesses some features which merit a brief notice. It is divisible into two subordinate portions. Upon the north of it is an extension of the Triassic formation, which forms a terrace of considerably greater altitude than the remaining portion. The southern portion has for its surface the Carboniferous formation and contains the Marble Cañon. The Triassic portion has received the name of the Paria Plateau, and the other has throughout this work been called the Marble Cañon platform.

The Paria Plateau presents some very instructive considerations in connection with the recession of cliffs. To appreciate them it is necessary to glance at the structural, topographic, and stratigraphic relations. An examination of the map will show that this plateau consists of a mass of Triassic beds which project far beyond the main line of the Vermilion Cliffs. At the village of Paria the main front of the Vermilion Cliffs terminates abruptly. The marginal line of the Triassic formation here changes its trend, running southward along the Kaibab wall for a distance of nearly 30 miles; then swinging easterly in a large semicircle reaches the Colorado at the head of the Marble Cañon. In this semicircle the Triassic Cliffs are the exact counterpart in all respects of the main Vermilion Cliffs west of Paria village; only the line of frontage has for some reason been left far in advance of the main line. It is to be remembered here that the Paria Plateau is separated from the Kaibab mass by the great East Kaibab mono-

cline, which throws down the former (or more properly raises the latter) about 3,500 feet. The same relative downthrow affects in varying amount the Marble Cañon platform.

This southward projection of the Triassic terrace illustrates in a very complete manner the effect of a fault upon the recession of cliffs when the fault runs in a direction perpendicular to the trend of the cliffs. The cliff extending away from the fault on the side of the downthrow has a diminished rate of recession. On the side of the upthrow this rate of recession is increased. The two rates are of course considered relatively to each other. This fact is of repeated application in the Grand Cañon district, and indeed throughout the Plateau country generally. Along the line of the terraces the great faults run perpendicularly to the trend of the escarpments, and the same effect is in each instance produced upon the rate of recession. A case quite homologous to the Paria Plateau is seen at the north end of the Sheavwits platform. Here the Hurricane fault throws up the Uinkaret side, and depresses the Sheavwits side. Upon the sunken side the Trias and Jura come in, occupying an area far in front of the main lines which terminate those formations upon the upthrow. Still again at the base of the Grand Wash fault, near the Colorado River, a patch of Trias is preserved under circumstances quite similar.

The cause of this retarded rate of recession is not far to seek. It is merely a special case of the general law that erosion is more rapid (*ceteris paribus*) upon high levels than upon low ones. It is so for two reasons. In this region at least—and the same is true of most other regions—the rainfall increases with the altitude. So also does the factor of transportation. For the higher the locality the greater are the slopes of the streams which flow away from it, and the more rapidly do they remove the débris produced by weathering. But the more rapid removal of débris in turn quickens the rate of weathering and disintegration, for the exposure of the rocks becomes greater. This law is repeated over and over again, and its verity illustrated on every hand throughout the Plateau Province. Those regions which have been elevated most have been most degraded by erosion; and inversely.

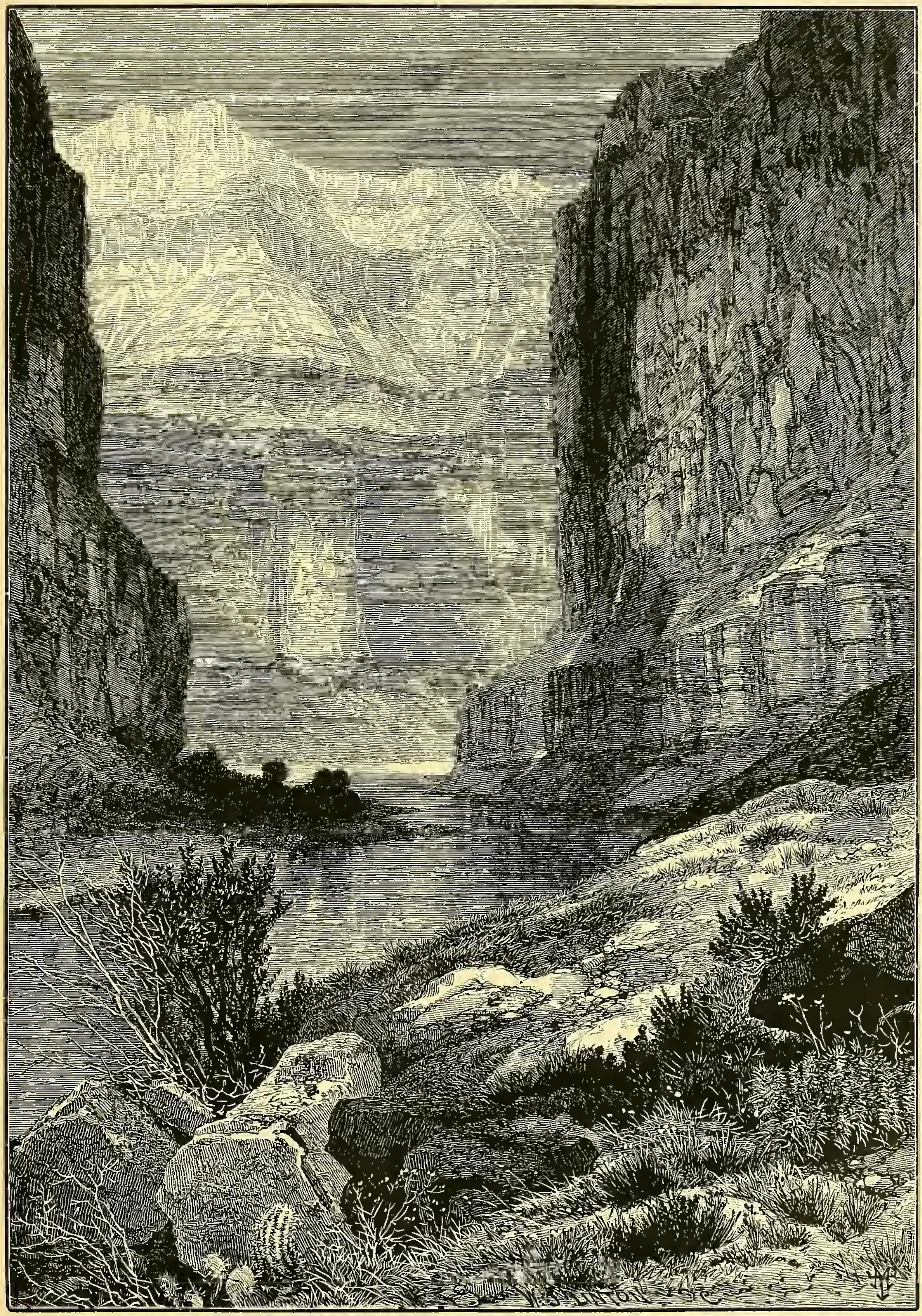
The Paria Plateau also exhibits some interesting facts in relation to its

drainage system. We have noted upon the Kaibab that the intricate network of surface-ravines everywhere conforms to the structural and mean topographical slopes. Whichever way the rocks dip, that way the ravines run. We also noted the very striking exception of those valleys, or continuous, single line of valleys upon the summit, of which De Motte Park is the most conspicuous; and we explained the considerations which led to the inference that the parks are the vestiges of a very ancient river valley existing before the development of the present structural features of the plateau, while the other ravines are of very recent origin and posterior to that structural development. In the Paria Plateau we have an analogous state of affairs. Its surface is covered with a network of drainage channels, often becoming very sharp, narrow cañons, cutting deeply into its platform. Most of these conform to the structural slope of the plateau. But there are two valleys which form conspicuous exceptions. One of these is the Paria River, which heads in the great amphitheater of the same name in the terraces between Table Cliff and the Paunságunt. This river is everywhere independent of the structural slopes. In general it runs against them, but along the eastern limit of the Paria Plateau its course is parallel to the strike of the strata. Into this river the entire drainage of the plateau is gathered. Thus, while the Paria River is older than the structure and quite independent of it, the small surface channels of the plateau are quite dependent upon the structure, and no doubt are due to it. There is one more drainage channel of ancient date and independent of the structure. This is House Rock Valley, which lies along the base of the East Kaibab monocline. There is a very slight northeasterly dip to the whole platform, and against this dip both the Paria and House Rock valleys extend. The latter is very probably an ancient channel belonging to the same group of old tributaries of the Colorado as De Motte Park, the Toroweap, and Queantoweap. For a long stretch of geological time it has been dry and ceased to carry water; perhaps since the first establishment of an arid climate in Pliocene time. But although its course is now against the dip of the strata it is inferred that it was not so originally, and that the displacements are in part at least more recent than the epoch at which the river ceased to flow and to corrade its channel.

In the case of the ravines of the Kaibab we saw some reason to conjecture that they had their origin during the glacial period. So, too, with the surface channels of the Paria Plateau the same conjecture seems applicable. In this region the glacial period was not icy. No traces of glacial action are discernible in the country round about until we reach the loftier heights of the High Plateaus—9,000 to 11,000 feet above the sea. But there is reason to believe that glacial time is here represented by a rainy period coming in between the arid climate of the Pliocene and the arid climate of the Quaternary. In truth the evidence of this is decisive. It is therefore natural for us to look for just such traces of its former presence as this network of cañons, or as the ravines of the Kaibab. For the effect of a long-continued arid climate is to obliterate the smaller streams, to increase the areas, and diminish the number of subordinate watersheds. The return of a moist climate would revive the minor channels. But if the arid climate had prevailed for a long period, and if during its sway the country had undergone differential vertical movements, the revived channels would not necessarily occupy the precise places of their predecessors. That would depend upon how deeply the original channels had been engraved, how extensive or nearly complete had been their obliteration, and how strongly marked had been the intervening vertical movements. On the Kaibab and Paria plateaus these factors appear to have had such values that the moist climate of the glacial period gave rise to networks of channels, which were quite independent of any which may have existed there in the Miocene.

On the Paria Plateau not a solitary channel carries a living stream except the Paria River, which receives its supply of water from the much loftier and moister region of the High Plateaus far to the northward. The extinct channels flow into it, and have directions which are very plainly determined by the general dip of the Paria table, which is towards the northeast.

Wherever we turn in the Plateau Country the drainage is constantly bringing up many interesting problems and suggestions, and happily also supplies answers more or less complete to many questions. I do not know of any other region where this subject is so fruitful or so entertaining. The



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relations of the drainage to the structure are so plain and so striking that the attention is always arrested by it and the facilities for putting the facts together in their normal sequence are unrivaled.

The Marble Cañon platform presents but few considerations, and those of the most patent kind. Like the Grand Cañon platform, it consists of Carboniferous strata, with a considerable number of Permian remnants scattered over it. The same northward dip of 50 to 100 feet per mile is everywhere noticeable, and has the same relative importance, because of the great distance over which it prevails. The great feature of the platform is, of course, the Marble Cañon. Mr. Holmes has given us a sort of bird's-eye view of this chasm, as seen from the lofty heights of the Kaibab. (Atlas Sheet No. XIX.) If the Grand Cañon were not hard by, and if its wholly incomparable magnitudes and grandeur did not belittle everything with which we might think of comparing it, the Marble Cañon might be the theme of some enthusiastic description. Though far inferior to the Grand Cañon, it surpasses all others in the grandeur and power of those features which are the exclusive attributes of cañon scenery.

The Marble Cañon begins at the Echo Cliffs. Here the river is almost in the open country, its banks being only 200 to 300 feet high. It has just emerged from the central mesas of the province through the Glen Cañon. Turning sharply to the southwest, the river begins at once to burrow into the Carboniferous platform. The beds dip almost exactly up stream, so that as the river falls, with its onward progress the crests of the walls absolutely rise. In fact, the progressive deepening of the gorge is due far more to the rise of the strata than to the descent of the channel. The declivity of the channel is about seven and a half feet per mile, while the rise of the strata is nearly eight times as much; and yet it should be borne in mind that an inclination of 1° is about equivalent to a slope of 92 feet per mile, so that the dip of the beds is really less than 1°—an inclination so small that the unaided eye finds difficulty in recognizing it. But as its effect is cumulative it gives to the Marble Cañon a depth of rather more than 3,600 feet at its lower end—a depth which it is very difficult to realize.

The cañon is very simple in form, being a trough with walls, which are for the most part nearly vertical. The width is about double the depth,

though this ratio varies somewhat. From what we have seen of the Grand Cañon we must conclude that the Marble Cañon would be much more impressive if its width were five or six times the depth, instead of double. Nothing resembling the great cloister buttes and temples is seen in the Marble Cañon. It is everywhere characterized by extreme simplicity. But the enormous expanse of vertical rock-face when seen from below is very impressive. Generally, in the deeper portions, the Red Wall limestone presents those buttresses with vertical flutings and scorings which characterize the same beds in the inner gorge at the Toroweap. It all looks very solemn, very architectural, and very imposing.

The only tributary which the Marble Cañon receives is the Little Colorado. There are some lateral amphitheaters, but they do not set back into the platform more than two or three miles from the river, and they cannot be properly called side chasms. But the Little Colorado is an important tributary. It heads far to the southeastward among the lavas of the Great Black Mesa of east-central Arizona. Its length is nearly 300 miles, and its watershed proportionately great; yet it contributes to the Colorado only a very small brook of water in the dry season. In flood time, however, the volume is large, for not only is the watershed extensive, but it is quite lofty on the whole, being from 7,000 to 8,000 feet over a large part of it. At such altitudes the rainfall in the wet season is considerable. This stream is everywhere independent of the structural slopes. Its lower courses are nearly parallel to the principal structure lines. In the vicinity of the Little Colorado the greatest structural feature is the Echo Cliff monocline, and this monocline is nearly parallel to the lower courses of the tributary. But far to the southeast the main branch of the stream crosses the flexure transversely, entering the ascending slope of the monocline. It soon becomes apparent that this tributary had its course laid out long before the existence of any of the great structural displacements, and that it is as old as the Colorado itself. Its origin goes back to the earliest Tertiary time when the region first emerged from its lacustrine condition. No other supposition seems capable of explaining the situation of the Little Colorado and the independence of structural slopes which it betrays everywhere along its course.

It seems proper also to describe briefly the Echo Cliff monocline, since it is one of the most important in that great series of displacements which traverses the district from south to north. Everywhere it is a true monocline. It is known to extend more than a hundred miles south of the Colorado, and certainly reaches fifty miles north of the river. Upon the flank of the flexure the Permian Trias and Jura are upturned, forming lofty cliffs of very irregular aspect. Back of these the Cretaceous comes in as a series of steps. The irregular character of the cliffs is due to the considerable inclination of the strata, causing them to weather into sharp towers and needles of very irregular form, instead of the systematic and regular profiles which are generated where these beds are horizontal. The total downthrow of the monocline varies greatly from place to place, but along those portions where it has been well observed the total displacement ranges from 3,500 to 4,000 feet. Its age is Tertiary, and probably very nearly coëval with the East Kaibab monocline; in other words, rather late Tertiary. The proof of Tertiary age is conclusive, since the flexure bends the Cretaceous beds wherever it approaches them and its northward continuation involves the Eocene.

CHAPTER XII.

THE GEOLOGICAL HISTORY.

Early Paleozoic conditions.—Silurian strata.—The great unconformity at the head of the Grand Cañon and its significance.—The beginning of the Carboniferous.—Inferences as to the condition of the region in Carboniferous time and during the Mesozoic.—Uniformity of conditions over great areas.—Diversity of character in the beds considered in respect to vertical range.—Shallow waters throughout the entire period of deposition.—The conditions in Cretaceous time.—Coal and carbonaceous shales.—Constant position of the surface of deposition.—Paradoxical nature of some of the problems presented.—Views concerning the mode of deposition in shallow waters of great area.—Relative distribution of land and water at the close of the Cretaceous.—Disturbances at the termination of the Mesozoic.—Unconformity of the Eocene and Cretaceous.—The advent of Eocene time.—Change of waters from brackish to fresh.—Great extent of the Eocene lakes and the causes of their creation.—The manner in which the lake of the Plateau Country was determined and its basin isolated.—Wide extension of the uplifting movement in the west.—Long persistence of the lakes.—Extent of Eocene deposits.—Origin of the plateau drainage system.—Stability of position in the principal drainage channels.—The great erosion during late Eocene time and during the Miocene.—Results accomplished at the close of the Miocene.—General method of the process of denudation.—Origin of the present Grand Cañon at the close of the Miocene.—Changes of climate from moist to arid.—Condition of the district at the beginning of the Pliocene.—Base level of erosion at that epoch.—Subsequent upheaval.—The development of the faults.—Coincidence of the faults and basaltic eruptions with the periods of upheaval.—Amount of uplift at this epoch.—Effect of the arid climate upon the topography.—The more recent upheaval and further development of faults.—Second period of base level.—The evolution of the Grand Cañon.—Rapid excavation of the inner gorge.—The glacial period.—Its effects upon the drainage channels.

We may now attempt the somewhat difficult task of extracting from the foregoing facts the history of the Grand Cañon district. Primarily, my intention has been to reconstruct only its Tertiary history. But, as in human affairs the events of any limited period are linked with those which preceded them, so here the Tertiary history is rendered more intelligible by reviewing whatever knowledge we may possess of the events which prepared the way for it. Prior to Tertiary time the records are very obscure, and the conclusions we may draw concerning such remote events are very few and of the most general nature, yet not without value.

Of the earlier Paleozoic conditions prevailing in the Plateau Province we know as yet but little. Already many perplexing problems have arisen

which will require much study to solve, and their solutions promise to be extremely difficult. Within the boundaries of the province exposures of rocks older than the middle Carboniferous are very few and far between Those which have received attention hitherto are confined to the Uinta Mountains and the lowest deeps of the Grand Cañon. Limiting our attention to the latter region, we find beneath that system of strata which we have thus far treated as Carboniferous a great variety of beds which range in age from the Archæan to the Devonian. Throughout the Kaibab and Sheavwits divisions we find the so-called Carboniferous resting sometimes upon highly metamorphic schists of undoubted Archæan age, sometimes upon the eroded edges of strata which have yielded Cambro-Silurian and Silurian fossils. In a single instance in Kanab Cañon Mr. Walcott found in a similar situation a very limited exposure of beds bearing fossils of Devonian age. In general, the rocks classed as Carboniferous rest upon the Archæan, while the older Paleozoic beds come in only at intervals. The contact is always unconformable and usually in a high degree. The horizontal Carboniferous beds appear to have been laid down upon the surface of a country which had been enormously eroded and afterwards submerged. In the Grand Cañon this single fact is indicated to us throughout the length of a long, narrow, and tortuous cut thousands of feet in depth. But if we pass westward or southward, beyond the limits of the great Carboniferous mass, we find a vast region where a similar state of facts is presented. The Sierra country of central and western Arizona, of Nevada, and western Utah shows remnants of the Carboniferous resting with great unconformity upon older Paleozoic rocks and upon the Archæan.

In the chapter on the Kaibab (Chap. IX, Pl. XXXV) I have spoken of the great unconformity displayed at the head of the Grand Cañon. Probably there is no instance to be found in the world where an unconformity is revealed upon such a magnificent scale, and certainly none amid such impressive surroundings. It is all the more suggestive because it is the type and symbol of a great fact which prevails over a region large enough for an empire. It assures us that in early Silurian time this region received enormous deposits of detritus which were faulted and flexed; that they were afterwards raised above the waters with the accompaniment of

volcanic action; that they were ravaged by an erosion commensurate with the grander examples of that process which are proven to have occurred in much later stages of the world's history; and that the region was again submerged.

With the Carboniferous began that long era of deposition which extended without any real break into Tertiary time. The record of each period seems to be complete in the strata, and the deposition was apparently continuous over the area of the Plateau Province taken as a whole, though here and there we may detect evidence of a brief interruption in some small areas. There are some general facts connected with this process of accumulation of strata which merit special notice.

(1.) The strata of each and every age were remarkably uniform over very large areas, and were deposited very nearly horizontally. In the interior spaces of the province we never find rapid increments or decrements of the strata. They do indeed vary in thickness, but they vary in the most gradual manner. Around the old shore lines, however, which form the present borders of the Plateau Country, we find the volumes of the strata much larger than elsewhere. But as we depart from them towards the heart of the province, we observe, in the course of two or three leagues, a considerable diminution in their thickness, and thenceforward the attenuation is so slow that we discover it only by comparing correlative sections many leagues apart. Very analogous is the constancy of lithological characters. As we trace the individual beds from place to place, we find their composition to be as persistent as their thickness. The sandstone of a given horizon is always and everywhere a sandstone, the limestone a limestone, the shale a shale. Even the minuter structure of the beds is similarly maintained, and features which are almost abnormal are equally constant. The Jurassic and Triassic sandstones are everywhere cross-bedded after their own marvelous fashion. The singular cherty limestones at the summit of the Carboniferous are quite alike on the brink of the Grand Cañon, at the junction of the Grand and Green rivers, and in the borders of the great Black Mesa at the south. The curious Shinarump conglomerate is the same in Pine Valley Mountains, in the terrace at Kanab, at the base of the Echo Cliffs, and in the Land of the Standing Rocks. The lower Triassic shales

and upper Permian shales, with their gorgeous belts of richest colors and beautiful ripple-marks, and with their silicified forests, have hardly varied a band or a tint from the brink of the Sheavwits to the pagoda-buttes of western Colorado. Still there are exceptions. The great Jurassic white sandstone fades out from northwest to southeast, and we are in doubt, at present, whether it failed of deposition or is blended with the Trias. Other members might be mentioned which undergo slow changes from place to place. But such changes are always very gradual. Nowhere have we found thus far what may be called local deposits, or such as are restricted to a narrow belt or contracted area.

All of these strata seem to have been deposited horizontally. Even the base of the Carboniferous has a contact with unconformable rocks beneath, which was but slightly roughened by hills and ridges. In the Kaibab division of the Grand Cañon, while the great body of Carboniferous strata was horizontal, we may observe near the brink of the inner gorge a few bosses of Silurian strata rising higher than the hard quartzitic sandstone which forms the base of the Carboniferous. These are Paleozoic hills, which were buried by the growing mass of sediment But they are of insignificant mass, rarely exceeding two or three hundred feet in height, and do not appear to have ruffled the parallelism of the sandstones and limestones of the massive Red Wall group above them.

(2.) Another consideration is as follows: as we pass vertically from one formation to another in the geological series, we observe the same diversity of lithological characters as is found in other regions. The limestones occur chiefly in the lower Carboniferous, and in very great force. At the summit of the Carboniferous also are 700 to 800 feet of calcareous strata. But in the Mesozoic system limestones are rare, and constitute but a very small portion of the volume. By far the greater part of the entire stratigraphic column is sandstone, and the various members of this class show great diversity of texture and composition. Some are excessively hard adamantine quartzites, very many are common sandstones in massy beds. By small gradations these pass into sandy shales, containing more or less argillite, and such shales form a large proportion of the bulk of the Permian and Trias. These shales in turn pass into marly beds,

which have vast thickness in the Cretaceous and form a considerable portion of the Eocene. Beds of gypsum are also frequent, forming thin separating layers in the shaly divisions, and sulphate of lime is a very important ingredient of the arenaceous strata from the base of the Carboniferous to the summit of the Jurassic. Besides its occurrence in distinct bands of nearly pure gypsum, it plays the part of a cement in the sand rock, and is also richly disseminated in the form of selenite in the sandy shales. On the other hand, there is a marked absence of such rocks as clay-slate. The slaty structure and composition has not hitherto been observed anywhere, so far as I know, and though argillaceous rocks are very voluminous in the Cretaceous they are charged with calcareous matter, and are very distinct from the ordinary clay-slates of the Appalachians.

Thus it will be noted that while the strata are remarkably homogeneous in their horizontal extensions, they are very heterogeneous in vertical range And this heterogeneity is found not only in the chemical constituents, but also in the texture and in the mechanical properties of hardness, compactness, and solubility. This consideration is an important one, since upon it depends the result which is obtained by the attack of the eroding elements—the achitecture of the cliffs and profiles.

(3.) Another general fact of importance is, that during the Mesozoic ages the surface of deposition was maintained very nearly at sea-level throughout the entire province. With regard to the Carboniferous strata it does not yet appear that the same was true. From such meager knowledge as we possess, there may be some reason for the opinion that the Carboniferous sea had a considerably greater depth during the earlier and middle portions of that age than during the later portion. The lower Carboniferous strata (Red Wall group) consist chiefly of limestones, and the overlying lower Aubrey group corresponding to the coal measures is a series of sandstones of exceedingly fine texture and often gypsiferous. There is a notable absence in these beds of signs of very shallow water, such as ripple marks, cross-bedding, coarse clastic material, and littoral remains, organic or otherwise. The fauna, as usual, is an unsafe guide, and must be regarded as non-committal. On the other hand, there is no reason to suppose that the depth was at all profound. It is rather by contrasting the total absence

of the signs of very shallow water with the presence of decisive signs of it in the Mesozoic and Permian, that we are drawn to the inference of somewhat greater marine depths in the early and middle Carboniferous.

In the upper Aubrey series we come upon some indications of shallow water, and from the base of the Permian upwards these are ever present. In the Permian, Trias, and Jura we find instances of those peculiar unconformities by erosion without any unconformity of dip in the beds. Perhaps the most widely spread occurrence of this kind is the contact of the summit of the Permian with the Shinarump conglomerate which forms the base of the Trias. Wherever this horizon is exposed this unconformity is generally manifest. Between the base of the Permian and the summit of the Carboniferous a similar relation has been observed in numerous localities, and there is a similar instance in the lower Trias. It has also been detected between the Trias and Jura, and between the Jura and Cretaceous. We are tempted to ask here, whether such unconformities, without the slightest trace of permanent displacement in the strata, may not have been due to oscillations in the regional sea-level rather than to movements of the land?

One of the more striking features of the lower Trias is the occurrence of a vast abundance of silicified wood. It is not uncommon to find large tree trunks imbedded in these shales in good preservation. They are also found in a fragmental condition among the pebbles of the Shinarump conglomerate. These petrifactions are found over a wide extent of country from the Sheavwits Plateau along the front of the Vermilion Cliffs to the Paria, and again far to the northward at the base of Thousand Lake Mountain in the district of the High Plateaus.

These occurrences and others, which will soon be specified, point decisively to the inference that during the great era of accumulation, lasting from the closing stages of the Carboniferous to the Eocene, the surface of deposition never varied far from sea-level, and now and then the waters retreated from it, but only for very brief periods. On the whole the deposition proceeded almost continuously. It necessarily follows that in the long run the underlying beds sank deeper and deeper as the newer ones were piled upon them. This fact is but a repetition of what is found in other regions where the deposition has been very heavy. The strata sub-

sided as rapidly as they were formed. It was true of the Appalachians, of the Pacific coast, of western and central Europe, and I think the same is true of all the areas of great deposition throughout the West.

When we reach the Cretaceous age we find that a little more light may be thrown upon the physical condition of the province, though much less than might be wished. So large are the areas where this series is the surface of the country, and so readily does the mind restore it to the places from which it has been denuded, that we feel almost as if we saw this great formation in its entirety. Wherever we turn in the Plateau Province the Cretaceous tells us the same story. All over its extent it is a lignitic and coal-bearing formation. We find coal or carbonaceous shales from the base of the series to the summit. Very abundant also are the remains of land plants in recognizable fossils, and these fossils occur not only in the carbonaceous layers but in the sand-rock and marls as mere casts or impressions of wood and leaves. Intercalating with these are many calcareous layers which yield marine mollusca in the lower and middle Cretaceous, and brackish water mollusca in the upper Cretaceous In a word, the parallelism, so far as physical and organic conditions are concerned, between the Cretaceous of the Plateau Country and the Carboniferous coal measures of England, Pennsylvania, and Nova Scotia, seems perfect. What the Carboniferous age was to the Appalachian region, such was the Cretaceous age to the great mountain region of the West.

A careful scrutiny of the facts presented by the Cretaceous strata of the Plateau Country brings up before us some very curious and perplexing problems. No one would hesitate to say that during the accumulation of these strata the surface of deposition must have been very nearly at mean sea-level. Yet the Cretaceous system varies from 3,500 to 8,000 feet in thickness in different parts of the province. The continuous area which they covered south of the Uintas surely exceeds 100,000 square miles, in which not a single mountain chain, not a hill, not even a perceptible undulation of the strata is known to have then existed.* It seems at first very

*There are some considerable areas of which we have but little knowledge, but we know the greater part of the province well enough to be sure that within the limits of observation the inference of the text holds rigorously. Very probably it holds good throughout the province.

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difficult to understand how so vast a mass of strata could have accumulated in such shallow waters and over so wide an area. And the difficulty becomes considerably greater when we recall the fact that coal was also accumulated at different horizons throughout the entire province If the sea were everywhere so shallow and if notable portions of its area were raised above the surface sufficiently to permit the growth of land vegetation, it would seem difficult to account for the transportation and diffusion of so large a mass of sedimentary materials over the entire expanse. Possibly some of the difficulties will be lightened by the following suggestions

Although to the eye the strata show no marked inclinations excepting such as we know have been produced in later periods, still there may have been, and probably were, very feeble slopes too small to be detected by the eye, and these feeble slopes if continued for any great distance would carry the surface down hundreds of feet. A slope of one degree means a difference of level of a thousand feet in less than eleven miles. Hence there is no difficulty in imagining that while some tracts were exposed just above the water level, there were still larger ones where there may have been more than a hundred fathoms of water. But it should seem that shallow water, provided the shallowness be not very extreme, would tend to a wider and more uniform distribution of sediments than waters which run off into great depths. The currents having less depth of cross-section would move more rapidly and constantly, while currents moving outward into deeper water lose velocity and transporting power. So far, then, is the shallowness of the Plateau sea from being an obstacle to our comprehension of the state of facts which the region presents, that it may be the key to the mystery. One of the most striking facts to be explained is the persistency of lithological characters over large areas and the very slight and gradual variations in the masses of strata from place to place. If these sediments had been brought down by rivers to a shore from which the waters steadily and rather rapidly deepened seawards, we might have looked for enormous masses of littoral beds which rapidly thinned out as they receded from the shores; for the moving currents might be expected to lose themselves in the deepening water. But with shallow waters, whatsoever currents might be generated—whether from tides, from large rivers, from oceanic drift, or from prevailing

winds—would persist as far as the depths remained shallow. Some such explanation as this, if it be tenable, would greatly assist us in explaining the wide diffusion of cross-bedding displayed in the Jura-Trias. It is generally accepted as an explanation for ripple marks that they are formed in shallow and moving water, and ripple marks are almost as abundant here as cross-bedding.

It would be extremely interesting to know what was the relative distribution of land and water over the western part of our continent in the closing periods of the Cretaceous. In a general way we know that the greater portion of the West was submerged. We also know that considerable land areas existed there. Sometimes we can point with confidence to a particular area and assert that it was land in Cretaceous time, but as a rule we are in doubt about the land areas. The largest piece of terra firma which is known was the Great Basin area, and even here we are unable to fix more than a small part of its shore line. We are reasonably confident that some and perhaps most of the great mountain platforms of the eastern ranges were above the waters with submerged valleys between them. We also know, and the fact is a momentous one, that nearly the whole of the vast region of the West corresponded in its physical condition to what we have inferred for the Cretaceous age of the Plateau Country. But detailed knowledge of the geography of the land areas in that age is exceedingly meager. Perhaps, however, we may make some very general statements which are not without value.

We cannot as yet affirm confidently that the Cretaceous ocean stretched from the lower Mississippi to the Pacific Ocean; but the facts now known indicate that if the two oceans were separated in that age the separation was only by a very narrow land area. We can travel from the Mississippi to the Pacific, between the thirty-fourth and thirty-seventh parallels, without being at any time more than fifty miles distant from some known mass of Cretaceous beds. If some gaps in existing knowledge could be filled up, we might be able to close up the vacant spaces in the distribution of the Cretaceous, and say that strata of that age once stretched continuously between the termini just mentioned. Indeed the only gap of importance is in the extreme southern part of Nevada and southern California. Every

indication we now have raises a presumption in favor of this complete connection; but it is unnecessary to speculate when the facts can be learned by observation.

North and south of this unexplored locality, where it is supposed that an arm of the Cretaceous sea reached out to join the Pacific, there lay land areas of considerable extent. The northern was the old mainland of the Great Basin; the southern was the Arizona land, of which such frequent mention has been made in this work. The northern area was much larger than the southern. It still remains possible that the two were one continuous area joined by an isthmus, or that the Arizona mass was a long Malacca-like peninsula projecting southeastward from the former.

At the close of the Cretaceous important vertical movements were inaugurated, which finally revolutionized the physical condition of the region. Around the borders of the Plateau Province some important flexures were generated at this epoch, and portions were uplifted sufficiently to undergo a large amount of denudation. Perhaps the most striking instance of this is the one described in the work on the High Plateaus extending from the eastern and southern flanks of the Aquarius southward to the Colorado. This area consists of Jura-Trias strata, from which the Cretaceous had been eroded before the deposition of the Tertiary. Beneath the lava-cap of the Aquarius the lower Eocene may be observed resting upon the Jurassic sandstone, and a little further westward it lies across the basset edges of the Cretaceous. Southeastward from the Aquarius and along the course of the Escalante River the same relation is inferred to have existed, but the great erosion has swept everything bare down to the Jura-Trias, and the evidence of the extension of the Eocene here is mainly indirect. But the two monoclines are in full view, between which the Escalante platform was hoisted, and their age is unquestionably pre-Tertiary and post-Cretaceous. These relations are repeated in many other localities, and they indicate to us very decidedly that the Cretaceous closed amid important disturbances.

Still the deposition of strata was not yet ended. It went forward with seemingly undiminished rapidity, but under circumstances somewhat different from those hitherto prevailing. Soon after the advent of the Eocene

the waters became fresh, and remained so until they disappeared altogether. This change was not limited to the Plateau Country, but appears to have been general over the greater part of the western mountain region. In truth, I know of no more impressive and surprising fact in western geology than the well-attested observation that most of that area has been covered by fresh-water lakes, and that the passage from the marine to the terrestrial condition seems to have been through an intermediate lacustrine condition. The marvel is not in the fact that here and there we find the vestiges of a great lake, but that we find those vestiges everywhere. The whole region, with the exception of the mountain platforms and pre-existing mainlands, has passed through this lacustrine stage.

When we take account of the peculiar circumstances our surprise may diminish in some measure, and the facts thus described may seem natural enough. The uplifting of the western region was a movement which acted unequally over the continent. Some portions were raised more than others. It is also to be considered that some of the inequalities of the surface existed before this general uplifting began. The result of this inequality must necessarily have been the production of depressed basins and intervening watersheds. Whether these basins would be completely closed, so as to form great lakes, or whether they should have drainage freely to the ocean, would depend of course upon the relations of the new axes of displacement to the older topography. If the new displacements merely accent and increase the older features, we should hardly look for the formation of lake basins. But if the new displacements are in any marked degree independent of the old ones, and if their axes lie transverse or oblique to the older axes, the formation of lake-basins in a newly emerging country is inevitable; and if the area affected be very extensive the chances are that the basins will be either very large or very numerous—in any event covering the greater part of the area. Without speculating as to the cause, it may be laid down as a general fact that the broader displacements of the West which began in early Tertiary time are quite independent of the older topographies, and the production of lake-basins by the new emergence seems a necessary consequence.

It is apparent in any event that the Plateau Country formed one con-

tinuous lake south of the Uinta Mountains. The vertical movements which followed the close of Cretaceous time shut it off from access to the sea. If we are at liberty to go on as we have done and to draw broad inferences from the drainage channels concerning the mode of evolution, we can very quickly frame a theory of the distribution of those vertical movements. Thus we know that during Cretaceous time the Plateau area was wide open to the ocean towards the southeast, or towards the Gulf of Mexico. For the Cretaceous system stretches from the heart of the province clear across New Mexico and into Texas, with no other interruptions than some short mountain ranges, (themselves largely composed of Cretaceous strata), and such gaps as have very plainly been produced by Tertiary erosion. Let us assume that at the beginning of the Eocene, or very soon thereafter, the western and northwestern part of New Mexico was uplifted slightly more than regions either east or west of it; the axis of elevation trending nearly north and south. The effect would have been to make an almost, if not completely, closed basin of the Plateau Country.

With this hypothesis we are able to frame a very simple and intelligible account of the manner in which the Plateau Province finally was isolated in Eocene time from the ocean. In truth, three-fourths or more of its boundary had been marked out long before, perhaps as far back as the beginning of the Trias; and in the following way. On the northwest lay the Mesozoic mainland, now forming the Great Basin area. In some form or other the Wasatch was then in existence as a mountain range. So, also, the Uinta chain on the north of the province then existed, but probably did not project so far eastward as at present, and left a gap in the boundary along the course of the Green River. On the northeastern side of the basin some of the great Park ranges of Colorado were standing, though the sea may have washed their bases. But to the southeast the area was wide open to the Cretaceous ocean. On the southwest and south lay the Arizona mainland so often spoken of in this work. Whether this mainland was continuous with the Great Basin mainland we do not know as yet, nor is it material just here. If, now, the first effort of the elevating force which has raised the continent had acted with more effect upon the eastern than upon the western side of the basin, the result would have been to make this basin

a land-locked area like the Euxine. Its outlet would necessarily have been along the lower courses of the Colorado to the Gulf of California, or, perhaps, straight westward to the Pacific.

Having thus obtained a consistent view of the manner in which the great Eocene lake of the Plateau Province may have originated, it now remains to follow out such changes as are indicated in its subsequent history. It should seem that the passage from the brackish water to the fresh water condition was quite sudden, and as the same is true of widely extended areas outside of this region, we are apparently obliged to assume that the movement of which this was a result affected the entire western portion of the continent, and that it was one of elevation. A considerable number of large lakes being formed, the next process was the desiccation of these lakes and the evolution of river systems. So long as the region occupied a low altitude this process, we may infer, would be very protracted. Before a large lake can be drained its outlet must be cut down. But several causes in the present instance would combine to render this action very slow and feeble. The elevation being small, the declivity and consequent corrasive power at the outlet must be correspondingly small. Moreover, the waters issuing from a large lake contain little or no sediment; and sediments—sand, grit, &c.—are the tools with which rivers chiefly work in corrading their beds. Corrasion by clear water is an exceedingly slow process.

It is not surprising, therefore, to find that the lakes produced by the first action of the elevating forces persisted for a very long time. This persistence is a general feature of the Eocene lakes of the West. The Plateau lake seems to have been one of the largest and most enduring, for it did not wholly vanish until the close of the Eocene. The volume of sediment accumulated upon its bottom was very large, ranging from 1,200 to more than 5,000 feet in thickness, and these deposits represent Eocene time exclusively. Here we are confronted by the same paradoxes as those we encountered in viewing the Cretaceous condition of the region: a tract which is rising yet sinking; a basin which is shallow, which receives great thickness of deposits, and yet is never full.

At length we detect evidence of the gradual cessation of deposit and of the progressive upheaval of the country. In the chapter which treats

of the terraces we noted the fact that in the southern portion of the lake basin only the lower Eocene was deposited, while in the northern portion around the Uintas the whole Eocene formation is present. Whence we infer that the final desiccation of the lake began in its southern or southwestern portions, and that the lake shrank away very slowly towards the north, finally disappearing at the base of the Uintas at the close of Eocene time.

We must also infer that upon the floor of this basin, as it emerged, a drainage system was laid out. Such a drainage system would necessarily conform to the slopes of the country then existing. Taking the supposition already made, that the uplift was somewhat greater upon the eastern than upon the western side of the province, the configuration of the principal drainage channels would be very much like that now existing. The trunk channel would flow southwestward and westward, while the tributaries would enter it on either hand very much as the larger and older tributaries now do. The affluents on the south side are the San Juan, the Little Colorado, and Cataract Creek, which seem to be due to just such an original surface. On the north side of the Colorado the arrangement of the tributaries also seems to conform to the assumption. On this side the later movements of the strata have been such that the prevailing courses of the streams are almost always against the dips. But when we restore these displacements and deduce from them as nearly as we may the original conformation of the country, the positions of the tributaries at once become natural and easy of explanation.

The argument here adopted concerning the origin of the drainage system affords little scope for discussion. Rivers originated somehow. It seems almost a truism to say that they originated with the land itself, and that their courses were, in the first instance, determined by the slopes of the newly emerged land surface. No doubt there are many causes which may have changed the courses of rivers, and in the subsequent changes of position the original arrangement may have been lost and left no intelligible trace. On the other hand, there are certain conditions under which we may look for the highest degree of stability in the positions of drainage channels, and when we find such conditions to have prevailed continuously the

question of origin becomes at once important, for it indicates to us an initial configuration of the surface, which must be taken account of and never violated in all subsequent discussion. All inferences or speculations concerning later displacements and many other groups of facts must be kept in strict subordination to it.

The Plateau Country is one in which the conditions have been remarkably favorable to the stability of the larger drainage channels. On the other hand, it has been singularly unfavorable to the stability of smaller or local drainage channels. The Colorado and its larger tributaries—those tributaries which head in the highlands around the border of the province—exhibit everywhere incontestible evidence that they are flowing to-day just where they flowed in Eocene time. But the smaller tributaries are wanting altogether in some large tracts, and where they do exist they usually disclose the fact that they are of very recent origin and have been determined by surface conditions of recent establishment. In the remainder of this discussion these facts assume great importance.

With the final desiccation of the Grand Cañon district began the great erosion, which has never ceased to operate down to the present time. Concerning the details of that process we know but little, and we can only guess at its general character during the earlier stages. Erosion is here associated with a large amount of uplifting, and we may conjecture that as the uplifting went on the inequalities produced by erosion became greater and greater, the valleys grew deeper, and the intervening mesas stood in higher relief. This is merely an application of the general law that the higher the country the more deeply is it engraved by erosion and the greater are its sculptured reliefs. Much, however, must depend upon climate. But the Eocene climate of the West, so far as it is indicated by the strata and organic remains of that age, was moist and subtropical, and presumably the climate of the Grand Cañon district was similar.

During the latter part of Eocene time the degrading forces no doubt made great progress in destroying and removing the Mesozoic deposits, which I have shown originally covered the region. We cannot, however, in this district find any epoch separating the later Eocene from the Miocene. To all intents and purposes they formed here a single age. From the

time when the great erosion was begun until it reached a certain stage (to be spoken of speedily) not a single detail can be pointed to beyond the principal facts of elevation and erosion. We are, so to speak, passing a long interval of time in the dark. We must, therefore, stride at once from the middle Eocene to an epoch which may be provisionally fixed at the close of the Miocene. From this epoch looking backward the total change wrought upon the region up to that time breaks into view. But we know only the beginning and the end. The intermediate stages are discerned only by the imagination. Yet I am tempted here to view this period in a way which may be in some measure speculative, though not wholly so. Some deductions may be made from established principles governing erosion which may fairly claim to be something more than mere speculation.

At the close of the Miocene, or thereabout, the greater part of the denudation of the Mesozoic should have been accomplished, and it is worth while to inquire in what manner this work may have been done. In the fourth chapter of this book I have spoken of the general fact that the attack of erosion is directed chiefly against the edges of the strata and the steeper slopes, and operates but feebly upon flat surfaces. The entering cuts are made by the corrading streams. The whole region had, during the long interval of Eocene and Miocene time, undergone a great amount of uplifting, and this progressive movement itself constitutes a condition highly favorable to corrasion; for the higher the country rises the greater become the declivities of the streams, and of those factors which determine a stream to corrade the most potent by far is declivity. While the country rises, therefore, the streams are making the reliefs greater—are creating larger surfaces of edgewise exposure and longer and steeper slopes. Thus, every advantage is given the agents of erosion.

The area thus exposed to rapid denudation was a very large one, and the corrasion of streams apparently went on over its entire expanse, without any very great local variations of amount, except perhaps near the borders of the watershed. While the normal method of decay is expressed in the recession of cliffs, we must not suppose that single and comparatively straight lines of cliffs stretched across the whole region and slowly wasted

backwards. We should rather conceive of the platforms as being cut by a labyrinth of drainage channels, ramifying over their entire expanse, and as being attacked within and without, and all around—as a great conflagration spreads through every square, street, and alley of a city. A state of affairs quite similar to that suggested here seems to prevail at the present time in the interior spaces of the Plateau Province. The drainage basins of the Escalante River, of the San Juan, and indeed of that entire part of the Colorado which reaches from the junction of the Grand and Green to the head of Marble Cañon, are wonderfully dissected by countless cañons, which I am confident were in existence at this very epoch, though they have since been greatly deepened and otherwise modified.

It may also be of interest to inquire whether it is probable that cañons, architectural cliffs, buttes, and mesas existed in the Miocene, similar to those now occurring. The answer to this must be largely conjectural, but it seems to me that the probabilities are against such a topography. The present features of the region are no doubt favored greatly by an arid climate. Still we know that cañons and cliffs may be generated in moist climates. But under a moist climate, other circumstances and conditions must be of a very exceptional nature to produce such features, and even if produced, they are evanescent. An arid climate not only tends to produce, but also tends to maintain them. Under a moist climate the tendency is to reduce them to normal forms. Further than this it seems useless to speculate.

The first indications of specialized events are associated with the beginning of the present Grand Cañon.* About the time that the river began to cut into the Carboniferous strata, some important physical changes in the condition of the region took place, which have left their imprints upon the topography. The climate appears to have changed from moist to arid. In preceding chapters we have noted particular instances where this change manifests itself in the drying up of lateral streams. Perhaps the

* I use the term "*present* Grand Cañon" to designate the state of the cañon at the present time in the Carboniferous, in contradistinction to the more ancient state of the valley. All through this work the idea is kept in view that this valley in earlier times lay within Mesozoic strata, which have been swept away from the vicinity of the river, and now appear only in the terraces, fifty miles or more to the northward.

most instructive one is De Motte Park, on the Kaibab. A considerable number of others are still distinguishable. These indicate that as the Colorado began to sink into the Carboniferous strata, some cause dried up their very fountains, and they ceased to flow. No explanation seems at all adequate except the advent of an arid climate. If, then, we could fix the period at which this change of climate occurred, we should have strong presumptive reasons for selecting the same period as the one in which the present Grand Cañon originated.

We know that the Miocene climate of the West was moist and subtropical. This is indicated by the great extent of fresh-water lakes in some portions of the West, their abundant vegetable remains, and the exuberance of land life But the remnants of Pliocene time are usually of a different character. In the Great Basin we have many proofs of the arid character of that age, and it is equally evident throughout the Plateau Country that the Pliocene climate was in the main very much like the present. We cannot, it is true, correlate with precision any definite boundary between Miocene and Pliocene; but, with no unreasonable latitude, I think we may still say that the Miocene climate of the Plateaus was a moist climate, while the Pliocene was arid, and that the transition from one climate to the other occurred near the close of the former age or near the beginning of the latter.

At the epoch when the cutting of the present Grand Cañon began, no doubt the district at large presented a very different aspect from the modern one. While the greater part of the denudation of the Mesozoic had been accomplished, there were some important remnants still left which have been nearly or quite demolished in still more recent times. The basalts of the Uinkaret and Sheavwits have preserved some extensive Permian outliers, and even these must have shrunken greatly by the waste of erosion during the long period occupied in the excavation of the Grand Cañon. Although the basalts which cap Mounts Logan and Trumbull are certainly very ancient, and are older than the faults—or at least older than a great part of the faulting movements—there is no assurance that they are as old as the origin of the present cañon. Still I do not doubt that they go back nearly as far, and they are certainly much more ancient than the inner gorge at the Toroweap. At the time of their outpour large masses of Per-

mian strata overspread the region. These are not limited to the few remnants described on the Uinkaret, but we find the summit of the Permian similarly protected by basalt in many widely separated localities. Thus the Red Butte south of the Kaibab division of the cañon has a basaltic cap which seems to be about as ancient as that of Logan. In the San Francisco Mountains may be found remnants of the same formation protected by lavas, though our knowledge is not yet sufficient to give us any opinion as to how great an antiquity should be assigned to those eruptions. No doubt they are Tertiary, but whether Miocene or Pliocene is unknown. In the valley of the Little Colorado some Permian masses have been similarly protected by basalt and still reveal nearly or quite the entire series. The Sheavwits Plateau contains these remnants with basaltic coverings more abundantly and upon a larger scale than any other plateau. Thus there is a general accord of testimony that at the period of the older basaltic eruptions very large bodies of Permian strata lay upon the Carboniferous platform. In truth, it seems as if the summit of the Permian then constituted the surface of the country, just as the summit of the Carboniferous does now. The fact that the older basalts wherever found rest upon the same geological horizon, viz, the summit of the Permian, suggests to us the further inference that the region near the river was then flat and destitute of deep cañons and valleys, such as now exist there, and, therefore, destitute of great hills, buttes, or mesas. The meaning of this is a base-level of erosion. The rivers could not corrade, because they had reached for the time being their limiting depth in the strata. The work of erosion would then be confined to leveling the sculptural inequalities without the power to produce new ones or to augment the relief of old ones.* This, it is true, looks at first like drawing a very broad and rather remote inference from a very slender basis, and would not be justified at all if it were not in general harmony with a wide range of facts. Many facts take form and coherence around it which would otherwise seem mysterious. Let us illustrate.

The condition of base-level is one in which the rivers of a region cannot corrade. As a general rule it arises from the rivers having cut down so low that their transporting power is fully occupied, even to repletion. This, in

* For a brief exposition of the general idea of a base-level see the concluding part of Chapter IV.

turn, involves the correlative fact that no elevating force has acted upon the region for a long period of time.* For the most part base-levels are prevalent during a cessation of the uplifting force. The recurrence of upheaval terminates the condition of base-level. The declivities of the streams are increased, their energy augmented, and their corrasive power renewed. New features are then carved out of the topography, or older ones are embossed in higher relief. A period of upheaval, then, is one in which the sculptural features of the land are generated and increased; a period of quiescence or cessation of vertical movement is one in which these features are obliterated.† Now, in trying to form some conception of the process by which the great denudation of the Mesozoic was accomplished, we may suppose that the uplifting of the region went on (1) either at a constant or a slightly varying rate, or (2) through alternating periods of activity and quiescence. The results would be widely contrasted in the two cases. The former would give us an exceedingly rough and hilly country at all periods of the erosion; the latter would give us just such a country as we see at present. The inequalities produced during a period of upheaval would be smoothed off during the period of repose. As a matter of fact we may be confident that the upheaval in its later stages has been of the paroxysmal character. Of this the proofs are abundant.

We may then conjecture the reason for the somewhat remarkable fact spoken of in Chapter VI, that the same stratum or geological horizon is almost everywhere the surface of the interior platform of the Grand Cañon district. Before the last upheaval we may conceive of the region occupying the situation of a base-level in which the inequalities which may have existed were obliterated. We shall see more of this subject of base-level hereafter.

*Other causes might be suggested, but this no doubt is the predominant one.

†If it be suggested that a long time might have to elapse after the cessation of upheaval before the river would find its base level, I reply to the contrary. Corrasion at any level notably above base level is a very swift process. Our concrete ideas of corrasion are apt to be drawn solely from ordinary rivers, which are almost always close down to base level. But any marked increase in the declivity of a large stream would (*ceteris paribus*) enormously accelerate the rate of corrasion. After the periodic uplifts of the Grand Cañon district I doubt not that the corrasion of the river bed has been exceedingly rapid, and that the river has recovered its base level as often as disturbed in very short spaces of time, though grinding through many hundreds of feet of strata. This will appear more fully in the next two chapters.

I have in the preceding chapters shown that we find at this epoch the first indications of the existence of the great faults. It does not appear, however, that these faults all originated at exactly the same epoch, and it is certain that their respective amounts of displacement have increased very slowly and gradually with the lapse of time. Again, we cannot be sure that all parts of one and the same fault were begun at the same epoch. Indeed, the evidence is overwhelming that the development of these dislocations has been a very slow and gradual process, and all that can be said concerning their condition in the particular epoch of which we are treating (close of the Miocene) is that they first betray their existence at that time. Before this epoch we know nothing of them; and at the time in question they were of inconsiderable dimensions for the most part. Their formation seems to have been incidental to the uplifting of the platform which took place about the time the present Grand Cañon began to cut. But concerning the nature of this association it is useless to speculate. In all the range of geological phenomena I know of none more perplexing than a great fault, and until we have some semblance of a working hypothesis which may serve or help to explain them, it is useless to speculate upon the causes of particular cases.

We may also note the coincidence of the earlier basaltic eruptions with this period of uplifting and faulting. It has been noted as a fact of very general application, that volcanism is active during periods of upheaval, and becomes quiescent during subsidence. The relations of the two classes of phenomena in the Grand Cañon district appear to conform to the general rule.

The amount of upheaval which took place at the epoch in question may also be roughly estimated. It varies from 2,000 to 3,000 feet. The uplifting forces then suspended operations for a time, and the drainage system sought a new base-level. During this paroxysm of upheaval the outer chasm of the Grand Cañon was cut; the river corrading down to the level of the esplanade in the Kanab and Uinkaret divisions, but below that horizon in the Kaibab. The corrasion was probably done as rapidly as the country rose, or very nearly so. At first we may presume that only a narrow gorge was cut—like the upper portion of the Marble Cañon. But

the river found its base-level soon after the uplifting ceased, and the cañon slowly widened by the recession of the cliffs. In this stage of the development an arid climate reigned throughout the district. Its effect is apparent chiefly in two ways: 1st, in the paucity of lateral tributaries and in the meagerness of small details in the land sculpture, and 2d, in the sharpness and abruptness given to all the cliffs, valleys, and mesa profiles.

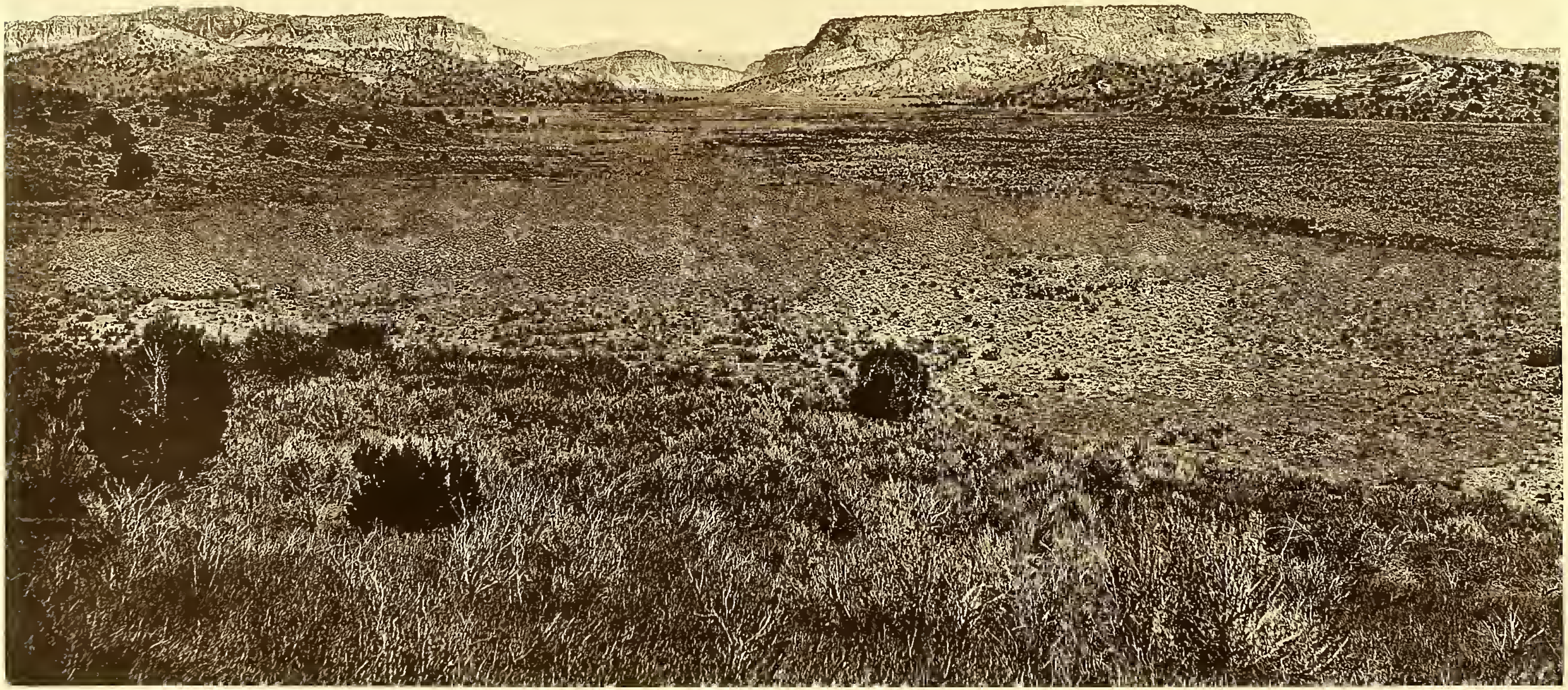
(1.) Allusion has frequently been made in previous chapters to the first mentioned effect of an arid climate. The only tributaries which remained during this period were the large and more powerful ones which had their sources far away in the highlands, around the margin of the watershed. Within the inner platform of the district no streams took their rise. The large tributaries continued to sink their lateral gorges in unison with the corrasion of the main river, but no new chasms were generated. On the contrary, some of the lateral tributaries, which for a time valiantly sustained a doubtful struggle for existence, at last succumbed and dried up, leaving their troughs opening into the main gorge far up near the summit of the cañon wall.

(2.) The sharpness and abruptness of profiles which characterizes the plateau scenery is not of recent origin, but dates back no doubt to the beginning of the Pliocene. An arid climate is an important factor in producing this effect. In such a climate weathering proceeds slowly. If the conditions are such as to produce a high efficiency in the agencies which transport the débris, the rocks will he left comparatively naked; little soil and talus will be formed, and little will be left. The attack upon the edges of the horizontal strata will thus be facilitated and the profiles will be determined chiefly by undermining. Such profiles are invariably cliffs.

We come now to the final upheaval which has brought the region to its present condition. The Colorado River, after remaining without corrasion at the level of the esplanade of the Cañon during the greater part of Pliocene time, at length resumed the operation of sinking its channel. A new paroxysm of upheaval set in; the faults increased their displacement; the volcanic vents reopened. This time the upheaval was greater than before, amounting probably from 3,000 to 4,000 feet. The narrow, inner gorge at the Toroweap was swiftly cut, and it is in this respect a type of

the lower deeps of the entire cañon. Everywhere the rapid corrasion of the deeper gorges is revealed. The epoch at which this latest upheaval took place, is no doubt a very recent one in the geological calendar. It began most probably near the close of the Pliocene. That it has now ceased is almost certain. No trace of present movement can be detected in any of the faults, and it is certain that no movement tending to increase them has taken place in those portions which have been scrutinized. In the Uinkaret some lava flows cross the Hurricane fault, and though they must be thousands of years old they are not dislocated. If any vertical movement is now in progress it is nowhere betrayed, and is unaccompanied by any of those collateral movements of faulting, which are usually associated with upheaval.

During the last stage of the evolution of the region we have to consider a very interesting episode. The glacial period here intervenes between the arid climate of the Pliocene and that of the present time. As has been already remarked, the glacial period here was not icy, but rainy, and very probably colder than the present. In some localities it began to excavate systems of local drainage channels and to carve out minuter details of topography. In truth the amount of this work which was done in that period was quite considerable. The most striking instance is to be found in the ravines of the Kaibab. The smaller drainage of the Paria Plateau is another instance. West of the Kaibab we fail to find such conspicuous traces of the glacial period. The explanation of their absence or feebleness may be the fact that those western plateaus have scarcely any slopes upon which such a drainage system could readily find foothold, while the slopes of the Kaibab summit and of the Paria platform are very considerable. The glacial period appears to have been of too brief duration to achieve any very great results in this district. It may have increased the corrasive power of the Colorado and tributaries by furnishing a larger water supply and there is decided reason for thinking that some of the cañons in the terraces were rapidly corraded and deepened at this time. Most of those lateral cañons in the terraces are slowly filling up with alluvium at the present time, but very plainly they were much deeper at no remote epoch in the past. The lower talus in some of them is completely buried and



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A CANON REFILLED WITH ALLUVIUM.

the alluvium mounts up on the breasts of the perpendicular scarps. In some cases a smooth floor of alluvium extends from side to side of what was originally a cañon valley. (Plate XXXVII.) The recurrence of a climate sufficiently moist to sustain a vigorous perennial stream would probably sweep out all this unconsolidated alluvium, and return the valley to its former condition of an ordinary cañon.

CHAPTER XIII.

THE EXCAVATION OF THE GRAND CAÑON.

The cañon is the result of two processes acting in concert—corrasion and weathering.—G. K. Gilbert on the subject of corrasion.—Nature and extent of the water supply of the Colorado.—The tributaries.—Springs in the cañons.—Evaporation.—Quantity of water flowing in the river.—Origin and character of the load to be transported.—Character of the tributary streams.—Extremely turbid condition of their waters.—Rainfall of the region.—Character of the sediment.—The declivity of the river bed in the Grand and Marble Cañons.—The rapids.—Relation of the bed-rock to declivity.—Rapids at the openings of lateral gorges.—General nature of the corrasive action.—Scouring action of the sand.—Weathering.—Conditions essential to the development of the topographical forms of the region.—The elevation of the country.—The horizontality of the strata.—Vertical heterogeneity and horizontal homogeneity.—Effects of an arid climate.

The excavation of the Grand Cañon and the sculpture of its walls and buttes are the results of two processes acting in concert—*corrasion* and *weathering*. In discussing these processes it is necessary to take into the account the peculiar conditions under which they have operated, and these are chiefly the climate and the elevation of the country.

In common parlance it is customary to say that the river has cut its cañon. This expression states but a small portion of the truth. The river has in reality cut only a narrow trench, of which the width is equal to the width of the water surface. It has also been the vehicle which has carried away to another part of the world the materials which have been cut away by both processes. Opening laterally into the main chasm are many amphitheaters excavated back into the main platform of the country. At the bottom of each is a stream-bed, over which in some cases a perennial river flows, while in other cases the water runs only during the rains. Like the trunk-river itself, these streams, whether permanent or spasmodic, have cut down their channels to depths varying somewhat among themselves, but generally a little less than the depth of the central chasm. These tributaries often fork, and the forks are quite homologous to the tributaries in the

foregoing respects. They too have cut narrow gashes no wider than their water surfaces. Down the faces of the walls and down the steep slopes of the taluses run myriads of rain gullies. When the rain comes it gathers into rills, which cascade down the wall-clefts and rush headlong through the troughs in the talus. Carrying an abundance of sand and grit, the waters scour out these little channels in much the same way as their united streams and rills cut down their beds in the amphitheaters and in the main chasm itself. But the work of corrasion by running water is limited to the cutting of very narrow grooves in the rocks, the width of the cutting at any given time and place being equal to the width of the water-surface of the stream. Corrasion alone, then, could never have made the Grand Cañon what it is. The amount of material removed by that process is but a very small fraction of the total excavation. Another process acting conjointly with the corrasion, and in an important sense dependent upon it, has effected by far the greater part of the destruction. This additional process is weathering. In order to comprehend the combined results of the two, it is necessary to study their action in detail.

Mr. G. K. Gilbert, in his excellent monograph on the Henry Mountains, has embodied a chapter on "Land Sculpture," which sets forth, in most logical and condensed form, the mechanical principles which enter into the problems of erosion. In his comprehensive analysis may be found a discussion of the conditions under which the sculpturing forces and processes achieve such abnormal results as we observe in the Plateau Country. The perusal of that chapter will give a delightful definiteness to the geologist's comprehension of the subject, and the reader, however learned he may be, will take great satisfaction in finding a subject so complex made so intelligible. The principles laid down by Mr. Gilbert will be adopted here and applied. I quote from his work the following:

"The mechanical wear of streams is performed by the aid of hard mineral fragments carried along by the current. The effective force is that of the current; the tools are mud, sand, and bowlders. The most important of them is sand; it is chiefly by the impact and friction of grains of sand that the rocky beds of streams are disintegrated.

"Where a stream has all the load of a given degree of comminution which it is capable of carrying, the entire energy of the descending water and load is consumed in the translation of the water and load, and there is none applied to corrasion. If it has an excess of load its velocity is thereby diminished so as to lessen its competence, and a portion is dropped. If it has less than a full load, it is in condition to receive more, and it corrades its bottom. A fully loaded stream is on the verge between corrasion and deposition. * * * The work of transportation may thus monopolize a stream to the exclusion of corrasion, or the two works may be carried forward at the same time.

"The rapidity of mechanical corrasion depends on the hardness, size, and number of the transient fragments, on the hardness of the rock-bed, and on the velocity of the stream. * * * The element of velocity is of double importance, since it determines not only the speed, but to a great extent the size of the pestles which grind the rocks. The coefficients upon which it in turn depends, namely, declivity and quantity of water, have the same importance in corrasion that they have in transportation.

"Let us suppose that a stream endowed with a constant volume of water is at some point continuously supplied with as great a load as it is capable of carrying. For so great a distance as its velocity remains the the same it will neither corrade nor deposit, but will leave the declivity of its bed unchanged. But if in its progress it reaches a place where a less declivity of bed gives a diminished velocity its capacity for transportation will become less than the load, and part of the load will be deposited; or if in its progress it reaches a place where a greater declivity of bed gives an increased velocity, the capacity for transportation will become greater than the load, and there will be corrasion of the bed. In this way a stream which has a supply of débris equal to its capacity tends to build up the gentler slopes of its bed and cut away the steeper. It tends to establish a single uniform grade.

"Let us now suppose that the stream, after having obliterated all the inequalities of the grade of its bed, loses nearly the whole of its load. Its velocity is at once accelerated, and vertical corrasion begins through its

whole length. Since the stream has the same declivity, and consequently the same velocity at all points, its capacity for corrasion is everywhere the same. Its rate of corrasion, however, will depend on the character of its bed. Where the rock is hard, corrasion will be less rapid than where it is soft, and there will result inequalities of grade. But so soon as there is inequality of grade there is inequality of velocity and inequality of capacity for corrasion; and where hard rocks have produced declivities there the capacity for corrasion will be increased. The differentiation will proceed until the capacity for corrasion is everywhere proportioned to the resistance and no further; that is, until there is equilibrium of action.

"In general, we may say that a stream tends to equalize its work in all parts of its course. Its power inheres in its fall, and each foot of fall has the same power. When its work is to corrade, and the resistance is unequal, it concentrates its energy where the resistance is great by crowding many feet of descent into a small space, and diffuses it where the resistance is small, by using but a small fall in a long distance. When its work is to transport, the resistance is constant and the fall is evenly distributed by a uniform grade. When its work includes both transportation and corrasion, as in the usual case, its grades are somewhat unequal, and the inequality is greatest when the load is least."

The foregoing analysis is applicable to the Colorado. Among the large rivers of the world considered as trunk streams draining large areas its condition and operations are exceptional, though by no means wholly unique. Nearly all large rivers along their lower and middle courses and along considerable portions of the larger tributaries have reached or nearly approximated to that condition of equilibrium of action which Mr. Gilbert speaks of, in which the transporting power is nearly adjusted without excess to the load to be carried; and they have little or no tendency either to corrade or to deposit. But the Colorado is corrading rapidly, and has doubtless done so during a great part of its history. To appreciate fully the conditions which determine and sustain this action it is necessary to study them in detail.

NATURE AND EXTENT OF THE WATER SUPPLY OF THE COLORADO.

The upper tributaries of this river* have their sources in lofty regions which are abundantly watered. But the trunk river itself and its lower tributaries, and also the lower portions of the Green and Grand Rivers, flow through regions which are exceedingly arid. Of the body of water which flows through the Grand Cañon all but a small portion comes from the far distant highlands. The quantity contributed by the middle regions is very small. Although there are numberless water-ways opening into the great chain of cañons, only a very few of them carry perennial streams, and these few living streams are mostly very small. The remainder, constituting by far the greater number of tributary chasms, convey spasmodic floods for a few days or hours at a time when the snows are melting, or when the infrequent showers and storms prevail. The river, however, receives accessions to its volume of water in the following manner. The country traversed by its middle courses is deeply scored with a vast number of profound side cañons, and the main stream itself flows at a depth varying from 1,000 to 6,000 feet below the general surface of the adjoining country. The water which falls upon the country is in great part absorbed by the rocks and sinks into the depths, where no doubt it finds subterranean channels. Surface springs are exceedingly rare, but in the depths of the main chasm and in the bottoms of the side chasms near the river the springs are plentiful, and in many cases very copious, sending forth clear sparkling waters, beautiful to the sight, but sometimes heavily charged with obnoxious salts. In the Grand Cañon especially are many springs of water, and not a few considerable streams of large volume emerging from the rocks in the lower depths. Most of them are good and fresh, and a few are saline and hot. The body of water thus supplied to the river is quite considerable, and it is important here to note the fact that it brings no sediment.

Between the junction of the Green and Grand and the lower end of

*Mr. Henry Gannett, geographer of the census, makes the total area of the drainage system of the Colorado 255,049 square miles, being second in extent of all the rivers of the United States which reach the ocean. That part of this drainage area which lies above the Grand Wash is given roughly at 165,000 square miles.

the Grand Cañon—a distance of about 500 miles—the Colorado has only two tributaries, which bring into it considerable bodies of water, and which at the same time run in the open air, as distinguished from subterranean streams. These are the San Juan and Little Colorado. The volumes of these rivers at their confluences are not accurately known, but during the greater portion of the year they are quite notable. They also bring great quantities of mud, sand, and gravel. Both enter the left bank of the river. All the other living streams are very small—in fact, mere rills—except at the times of irregular floods. On the other hand, the evaporation of the water in this part of the river in summer time must be very great.* The dryness of the air is extreme and the heat intense. In June, July, August, and September the midday temperature of the air is seldom below 90°, and often exceeds 110° Fahr., while the relative humidity is only from 0.3 to 0.4 of saturation. Still the river probably receives more water from the springs in the cañons and from the two larger tributaries than it loses by evaporation, and though the excess of this gain over the loss cannot be accurately valued I believe it to be considerable. Much importance is here attached to the fact that this increase in the volume of the stream in the cañons consists largely of water wholly free from sediment. It means an increase of transporting power in the river without an equivalent increase in the amount of material to be transported.

The quantity of water which the Colorado carries varies, of course, enormously from season to season throughout the year. A rough estimate may be made of its volume near its lowest stage. In the year 1877 Prof. A. H. Thompson gauged the flow of the Green and Grand Rivers near their junction, in the latter part of September, and found 4,400 cubic feet per second in the Green and 4,860 cubic feet per second in the Grand. The sum of the two, 9,260 cubic feet per second, is no doubt less than the flow in the Grand and Marble Cañons. The year was, so far as can be judged, very nearly an average one. At the time the measurement was made the river was very near its minimum.

*A water surface 500 miles in length, with an average width of 400 feet and an average evaporation of 0.4 inch per day from every square foot of surface, would lose by evaporation 407.4 cubic feet of water every second. This is equivalent to a stream of water 45 feet wide with an average depth of 3 feet flowing 3 feet per second. The rate of evaporation of 0.4 inch per twenty-four hours is, I believe, a low estimate for the Colorado in the great chain of cañons during the hot months.

ORIGIN AND CHARACTER OF THE LOAD TO BE TRANSPORTED.

We may now turn our attention to the material brought into the cañons constituting the load to be transported. Although the Colorado is a river which derives the greater part of its water and transported material from lofty regions at a great distance from the cañons, it still receives a notable amount of sediment from the Plateau Country contiguous to its banks. And it is interesting to note the conditions under which this sediment is contributed. The region adjoining the great cañons of the Colorado is so arid that it does not give rise to a single surface stream. The very few tributaries to the cañons which carry water enough to be worthy of notice have their sources far away in much loftier and moister countries. The rainfall of the region in question is not known, but it is doubtless exceedingly small, and if it be stated at 4 inches per annum for the region draining laterally into the Glen and Marble Cañons, this amount seems to be as large as present knowledge may justify. In the Grand Cañon district it is probably much greater, though still very small when compared with fertile regions. On the Kaibab, though the amount has never been measured, it seems as if 20 inches per annum would be a very low estimate; but this locality is quite exceptional. Rains sufficiently copious to saturate the soil and set the gulches running are very infrequent, and, perhaps, do not occur oftener than half a dozen times every year. But when they do come the consequences are very striking. The rills and washes are thick with mud and sand, and the water is loaded to its utmost capacity. There is no vegetation to form a sod and hold the earthy matters in their place. The instant a rill forms it is a rill of mud. The country being scored with numberless cañons and steeply sloping gulches, the rills and streams are gathered together with marvelous rapidity and plunge furiously into these narrow chasms, where they rush along with prodigious velocity. The traveler in such a cañon, who is admonished of the coming of a storm, cannot be too diligent in seeking a place of safety. The murmur of the falling rain is followed in an incredibly short time by the deafening roar of the torrent, which rolls madly down the chasm as if some great reservoir above had

burst its dam and discharged its waters. As it moves onward it sweeps everything loose in its way. Huge fragments of tons weight fallen from the cliffs above are bowled along with a facility that is highly suggestive. The water is charged to its utmost capacity with fine sand and silt, and it is somewhat surprising to see how much of this stuff a given quantity of water can carry. In the Mesozoic rocks it would not be an improbable estimate to say that these spasmodic waters carry nearly three times their own volume of fine material, and it is quite certain that they often carry more than twice their volume. Every explorer in this region can recite experiences of trying to obtain from some of the rills water for camp use by allowing a kettle-full to stand over night in order to settle, and finding in the morning an inch or two of dubious water on the surface of the vessel, with 7 or 8 inches of viscous red clay beneath and 3 or 4 inches of sand and grit at the bottom. The sediment thus transported is sand and clay. The rocks of the Mesozoic system are composed almost wholly of these two materials, the calcareous members being very few and of very small thickness; and such of the latter as occur are more frequently gypsum than calcite. The Permian also is similarly constituted, though having a few notable bands of arenaceous limestone. The cementing material of the sandy-clayey beds of the Trias and Permian is more or less gypsiferous, and many of the layers are highly charged with selenite. The ready solution of this cement yields an abundance of sand and clay in highly comminuted form, and every copious shower washes it along in great quantity.

The amount of this finer material which reaches the Colorado in the cañons is very great; and what is most striking, the contributions are not extremely irregular. In the summer time local showers, though infrequent in any given locality, are frequent enough in this portion of the Plateau Country as a whole. From any commanding point, which overlooks a very great expanse, distant showers may be seen on very many days of the hot summer. If we were to spend a week on such a point we might reckon with a high degree of probability upon one or more days in which heavy showers would be visible in different parts of the panorama. They are, however, extremely local, and rarely cover such large extents of country as the

thunder storms of the eastern States. It is not at all uncommon to see the rain streaks descending from a small cloud and falling upon areas no greater than three or four square miles. Still more curious is the formation of rain streaks without any cloud. When the season is showery many of the showers fail to reach the earth, the rain being completely re-evaporated in mid-air. It may thus be inferred that while rain is formed in the air daily throughout this region, only a small portion of it reaches the earth in showers sufficiently copious to saturate the soil and set the channels awash. Still, in an ordinary summer, a great majority of the days are somewhere marked with showers of sufficient volume to start the arroyas and cañons and pour a *debacle* of mud and sand into the Colorado. The river itself is rarely clear, and is rarely otherwise than turbid and muddy. In the latter part of September and early part of October, the river is in some years quite clear, and at its lowest stage of water displays that beautiful pistachio-green color which is seen in the waters of Niagara below the falls. At this season showers are infrequent. In the latter part of October, or in November, a rain storm, lasting from two or three to eight or ten days, may be looked for, and indeed rarely fails. It overspreads the entire region, and though the precipitation is not usually very copious on an average, yet it is so in many localities, and is always sufficient to flood many cañons which are normally dry, and to raise the water in the river very considerably. Immense quantities of sand and silt are then washed into the river, which is sometimes overburdened temporarily with sediment.

The greater part of the precipitation takes place in the winter months. Its amount varies more with the altitudes of the localities than with any other cause. Upon the higher levels it falls almost wholly as snow, and is usually very considerable. On the Kaibab the snow is always very heavy. Upon the lower and middle levels the precipitation in winter is more irregular when different years are compared. One year will furnish a heavy snowfall; another year will yield only a small amount of rain.*

* Our knowledge of the meteorology of this region is as yet very imperfect, especially as regards the precipitation of the winter and spring months. Such as we have is derived largely from the statements of the most intelligent of the Mormon people residing there. During the last six years I have had occasion to make many thorough inquiries of them and to converse with them at much length upon the subject. But the want of actual measurements of the amount of precipitation through a series of years is to be regretted. I can venture only so far as to give a general statement of what I am con-

While the precipitation upon the middle and lower levels—5,000 to 6,500 feet above the sea—is on the whole quite small, the transporting power of such water as runs into the river is very great. A cubic yard of running water in the Plateau Country probably carries several times more sediment than the same quantity of water in the Atlantic rivers. This remarkable difference is due to the following causes: In the first place the soil and comminuted débris of the plateaus is not held together by vegetation, but lies loosely upon the rocks and taluses, and is easily gathered up by rills. But chiefly the slopes are always very great, and as the transporting power increases enormously with the declivity the only limit to the quantity of material a given volume of water can carry is reached when the mixture becomes so viscous that its own internal friction is great enough to seriously retard its rate of motion. In the rivers which drain the Appalachian region the finer material is supplied in quantity insufficient to load the running waters to their full capacity, while the rainfall is very copious and the declivities considerable. In the prairies of the Mississippi Valley the declivities are small, while the water supply is great and the finer material superabundant. In the plateaus the water supply is small, while the declivities are very great and the fine material also is relatively in excess. This will sufficiently explain why the spasmodic streams of the plateaus are so much more heavily loaded with sediment than those of moister regions.

THE DECLIVITY OF THE RIVER.

The declivity of the Colorado in the Grand Cañon next requires our attention. Between the junction of the Little Colorado and the Grand Wash the absolute altitude of the river bed declines from 2,640 to 1,000 feet above the sea—a total fall of 1,640 feet. The distance measured along the median line of the water surface is 218 miles, giving an average fall of 7.56 feet per mile. But the rate of descent through the various parts of the cañon varies considerably. The following table, derived from the meas-

vinced is as near an approximation to the truth as can be obtained at present, and this statement must necessarily be very meager. The great irregularity when different years are compared is, I am satisfied, unquestionable.

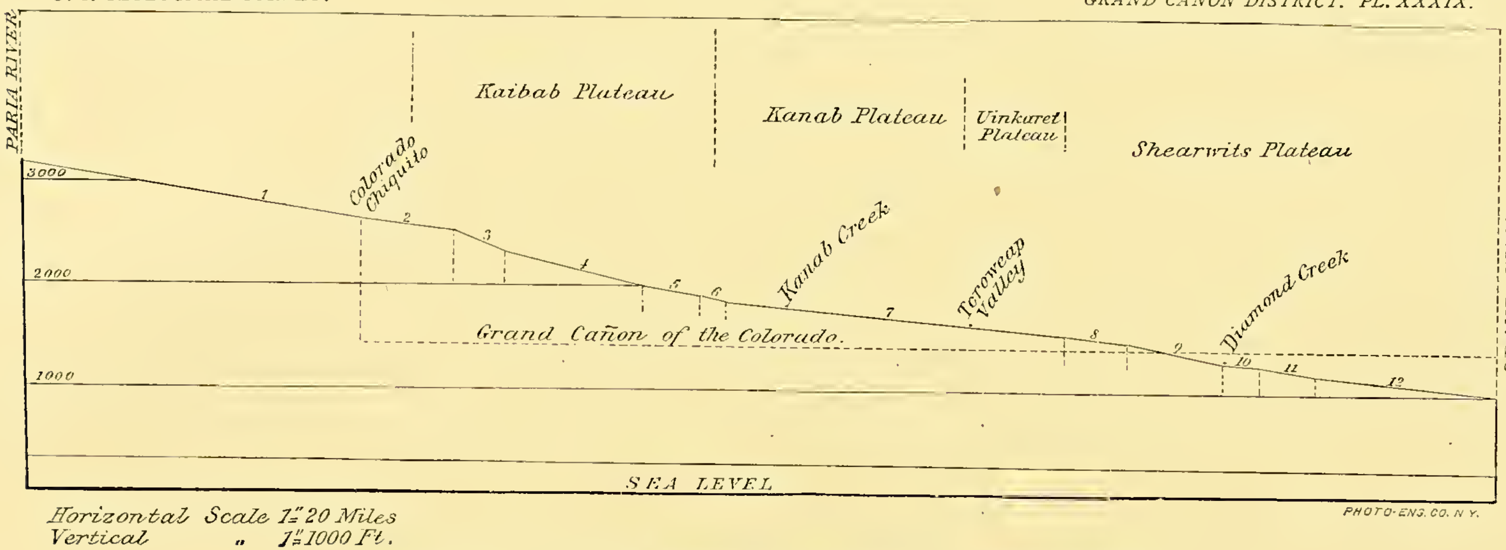
urements of Professor Powell, shows the varying declivity of the major portions, and the accompanying profile represents them graphically.

Subdivisions.	Distance in miles.	Total fall in feet.	Fall per mile.
From Little Colorado to Kaibab Division	9.6	60	6.25
Kaibab Division	58	700	12.07
Kanab Division	47.6	240	5.01
Uinkaret Division	19.2	100	5.21
Sheavwits Division	84	540	6.43
Totals	218.4	1,640	7.56

Moreover, the fall is very unequal in the various parts of the subdivisions of the foregoing table, in which the fall for each division is averaged without exhibiting the true profile in detail. The following table represents a nearer approximation to the real variations of declivity. In this table the entire length of the cañon is subdivided without reference to the individual plateaus, but in such manner as to embody portions of greater or less length, in each of which the declivity is not greatly varied. The numbers in the first column represent portions delineated in the accompanying profile and designated in the drawing by corresponding figures. In this table the Marble Cañon is included.

	Distance in miles.	Fall in feet.	Fall in feet per mile.
No. 1. Marble Cañon	65.2	510	7.82
No. 2. From Little Colorado to the granite	18.2	110	6.04
No. 3. Granite Falls on Kaibab	10	210	21
No. 4. In the granite to Powell's Plateau	26.4	320	12.13
No. 5. Around western base of Powell's Plateau	10.8	100	9.26
No. 6. Head of Kanab Division	4.8	50	10.42
No. 7. Main Kanab and Uinkaret Division	65.2	310	4.75
No. 8. Sheavwits Division to granite	12	70	5.83
No. 9. Granite to Diamond Creek	18	210	11.66
No. 10. Granite below Diamond Creek	7.2	25	3.47
No. 11. Granite below Diamond Creek	10.8	100	9.26
No. 12. From the Sheavwits granite to the end at Grand Wash	35	175	5
Totals	283.6	2,190	7.72

The foregoing table is the nearest approximation to the profile which the barometric measurements hitherto made enable us to furnish. But it by no means gives the true profile in detail. It still remains to give a verbal and general account of it. The entire extent of the river within



PROFILE OF THE RIVER BED IN THE GRAND AND MARBLE CAÑONS.

the cañon is a succession alternately of smooth reaches, with very small declivity, and swift rapids where the declivity is very great. In the Kaibab the smooth reaches are short, while the rapids are long and of great descent. In the Kanab and Uinkaret divisions the reverse is the case—the smooth stretches are long, the rapids short and much less frequent and powerful. In the Sheavwits division the proportion of the smooth to the rapid portions is between those prevailing in the Kaibab and Kanab divisions respectively. By comparing the distribution of fall with the nature of the rocks through which the river runs, it appears very clearly that the greater declivities occur in the Archæan rocks. The river enters the Archæan in two great bends, one in the Kaibab, the other in the Sheavwits. In the Kanab and Uinkaret divisions the river flows in the Silurian and lower Carboniferous. The Archæan rocks are, as a rule, much harder and are corraded with more difficulty than the others, and to this more obdurate character the greater declivities may be traced.

The rapids are, however, the results of two independent causes. (1) When the course of the stream lies in the hard rocks the rate of declivity is greater. The explanation is obvious. (2) The second cause is of a totally distinct nature. At the opening of every lateral chasm or side gorge a pile of rocks and rubble is thrown out into the main stream. Most of these side gorges are dry throughout the greater part of the year. But when the rains come their narrow beds are occupied with floods of muddy water, rushing downward with great velocity and often in great volume, bowling along fragments of all sizes from a few pounds to many tons. Thus an obstruction like a low dam is built across the river. The declivity of the side gorges is always much greater than that of the main stream. Their slopes are rarely less than 200 feet to the mile, except in those tributaries which, like Kanab Creek and Cataract Cañon, are of great antiquity. The minimum slopes of the beds of the great amphitheaters in the Kaibab are seldom so small as 200 feet to the mile. The power of a great flood rushing down such slopes is indeed formidable. When the torrents reach the river the larger fragments are dropped; for the maximum slope of the main stream (reckoned throughout any stretch exceeding four or five miles in length) never exceeds 25 feet to the mile, and the water, though enormous

in volume at flood time, has less velocity than the torrents of the side chasms. The river has, however, sufficient power to sweep onward masses of considerable size, which are rapidly ground up as they are rolled along.

It is apparent that in the work of corrasion an important part consists of the work of grinding up and destroying the masses which are brought into the main chasm by the spasmodic floods in the side gorges. Indeed, this constitutes by far the greatest part of the entire work. The coarse material—the large rocks, bowlders, and rubble which pile up at the mouth of the lateral chasm—are gradually spread out below the dam, and the tendency is to build up and increase the grade of the smoother reach below. But this tendency is quickly checked and brought to a stop by the increased power of the main current due to the increased slope. The body of fragments thus rolled in is of great amount in the aggregate. On the whole, the amount at the present epoch is not sufficient to prevent the river from cutting down its channel, though the process is of course greatly retarded. The river is still sinking its chasm in the strata. There are many stretches of comparatively still water where there is an equilibrium between the tendency to cut still deeper, and the tendency to build up the bottom by the accumulation of débris. But a great part of the river bed is in the bare rock of the Paleozoic and Archæan strata, and wherever it is so the corrasion is proceeding at a rapid rate. Still other cases occur where the rate of corrasion is retarded but not completely counterbalanced by the accumulation, and these no doubt constitute the greater part of the extent of the chasm.

The great corrasive power of the Colorado is due to the large quantity of sand which it carries, and the high velocity given to its waters by its great declivity. As we have already shown, the quantity of fine material brought into the cañons is very large and the supply is almost continuous throughout the year. As Mr. Gilbert has well shown, a river may be powerless to corrade when its waters carry no sediment, and also when the sediment is so excessive that it cannot transport the entire supply. Neither of these extremes is found in the Colorado. The waters are heavily charged but not overloaded. It must be noted, however, that in the smoother portions where the declivity is locally very small, the sand is often dropped,

and accumulates while floods are subsiding, but it is lifted and carried forward again when the waters increase. At low water many sand bars are formed in the still reaches, but they are changed and modified by every flood, and many of them are wholly swept away and reconstructed with each oscillation. The scouring action of the sand is highly efficient. It is seen on all the rock surfaces laid bare by the subsidence of the waters, and in all the large fragments rolled in from the side gorges. The rocks are full of pot-holes and covered often with bosses highly polished and ground by the sand-blast. The large bowlders which fall from the cliffs above, or which are brought in through the side gorges, are rapidly dissipated. The largest ones are deposited at the mouth of the gorge where the rapid is formed, and where they are exposed to the fullest energy of the current. The largest masses, if fully exposed to this action, can scarcely survive more than three or four years. Although the dissipation of the fragments in the Colorado has never, so far as I am aware, been watched and timed, we are not without the means of confidently inferring a very short duration of that process. In the hydraulic mines of California the water discharged against the gravel banks has been known to cut in a single year chasms from 12 to 20 feet deep in the hard basaltic pavements over which it flows. The actual time of operation is equivalent to not more than 100 days of uninterrupted activity. No doubt the instance here cited is an extreme case of rapid corrasion, and is not strictly parallel to that of the river. But a large river always charged with sand, and careering swiftly over a dam of rocky fragments, is a very strong case, if not an extreme one, and we may perhaps be led to regard four years as a long life for a rock-mass, six feet in diameter, exposed to the full and uninterrupted action of the stream.

Not all of the large fragments, however, are exposed to this continuous action, but many of them are out of water during the greater part of the year. At the opening of a side gorge the river is usually constricted, and in many cases the width is not more than one-third of the mean width. The coarse débris forms a deposit somewhat analogous to an alluvial cone.

Undoubtedly the corrasion is most efficient during the stages of high water. In many and perhaps in most rivers this is not true, or at least is not necessarily true, for the sediment brought down by floods in other

streams is often in excess of the actual lifting power of the water, and a portion of it is deposited. But in the Marble and Grand Cañons this is rarely so. The flood-water comes from far distant regions. In the Glen Cañon, where the declivity is notably less, any excess of load above the quantity easily transported (if any such excess ever occurs) is temporarily deposited. Reaching the Marble Cañon the greater declivity at once augments greatly the transporting power, and the torrent sweeps everything loose before it For six or seven weeks the corrasion goes on at a very rapid rate. Many reaches, which at low water are protected by sand and gravel, are swept bare, and for a time are subject to the full corrasive energy of the torrent. The water rises from 30 to 60 feet, attacking the slopes at the bottom of the gorge, which are ordinarily naked rock, and grinding them away at a rate which must be a rapid one during the time it is in operation.

Reverting here in a summary way to the two classes of rapids formed in the river, we find that they are due to two wholly distinct causes—1st, to the unequal hardness or resisting power of the strata in the bed of the stream; 2d, to the accumulation of piles of large fragments washed in through the lateral gorges. The greater number of rapids are due to the latter cause. The general characters of the two kinds, however, are strikingly different. Those which occur in the hard crystalline rocks are very long, and with some notable exceptions are less violent and headlong than the others, but they are also complicated with the second class of rapids, *i. e.*, those due to the bowlders rolled in from the side chasms. If we separate the latter effects, we find the effect of hardness of the strata to be a general increase of slope distributed with some approach to uniformity over many miles of length of the river bed. It is plainly so in the Kaibab and Sheavwits, and this effect is not at all obscured by the joint operation of both causes. The rapids of the second class are short and violent, as might have been inferred from the nature of the cause which produces them.

WEATHERING.

We have seen that the work of corrasion, pure and simple, is limited to the cutting of deep and narrow gashes in the strata and to the grinding up of the larger fragments brought into the channels. The widening of these cuts into the present configuration of the cañon and the sculpture of the walls are the work of the process which is termed weathering. By far the greater part of the material removed in the total process of the excavation has been broken up and comminuted by the action of atmospheric reagents, and their mode of operation is worthy of careful study. In the remaining part of this chapter I shall treat briefly of the more general conditions and features of this process, and devote the final chapter to the consideration of some of its striking details.

The peculiar cliff forms of the Grand Cañon, and indeed of the province at large, would hardly be possible in any other country, for no other country presents all of the conditions which are necessary for them. These conditions may be summarized as follows: (1) The great elevation of the region. (2) The horizontality of the strata. (3) A series of strata containing very massive beds, which differ greatly among themselves in respect to durability, but each member or subordinate group being quite homogeneous in all its horizontal extent; in a word, heterogeneity in vertical range and homogeneity in horizontal range. (4) An arid climate.

I. It is at once apparent that great elevation is essential to the production of high reliefs in the topography by the agency of erosion. Only in a high country can the streams corrade deeply, and it is by corrasion that the features of this region have been originated and blocked out. The elevation, however, is a condition whose immediate consequences are associated with corrasion, while it affects weathering only secondarily or remotely. The principal effect is the determination of the heights of the cliffs and the magnitudes of the topographical reliefs in general. All this seems so obvious that discussion is superfluous.

II. No less obvious is the effect of the horizontality of the strata. The long flat crestlines, the constant profiles maintained for scores of miles along

the edges of each stratigraphic series, would not be possible otherwise. To appreciate this it is only necessary to glance at the effects which have been produced by the monoclines which at wide intervals interrupt the continuity and constancy of the cliffs. No wilder scene can be imagined than the pinnacles, towers, and domes which bristle upon the flank of a great flexure, like the Echo Cliff or Water Pocket folds.

III. The condition of horizontal homogeneity with vertical heterogeneity presents considerations some of which are as obvious as the foregoing, while others are extremely complex. It is clear that if the strata now forming the escarpment of the Vermilion Cliffs had varied rapidly from point to point in respect to the thickness of individual members, or in respect to their lithological characters, the action of weathering would have varied accordingly. The profiles would undergo rapid changes of form along the front. In truth, there is a certain amount of variability of just this character in that escarpment. The Vermilion Cliffs in the valley of the Virgen differ notably in detail from what they are at Kanab and near the Paria. The enormous sandstone member dwindles in thickness from west to east, and other members less conspicuous gradually lose identity, and the resemblance of the two widely separated portions of the wall is only general. But the change along the front is very slow and is nowhere abrupt.

The vertical heterogeneity is the character which gives complexity to the profile. Where the beds are numerous and where they differ among themselves as to durability, the profile becomes very complicated, like a very elaborate series of horizontal moldings. The extreme of simplicity is found in the Jurassic sandstone, where the cliff consists of a single massive stratum 800 to 1,000 feet thick and homogeneous from top to bottom. Those more complex results which follow the action of weathering upon vertically heterogeneous strata will be discussed in the next chapter.

IV. The effects of an arid climate are by no means simple nor intelligible at a glance. They appear only upon analysis, and the analysis must take cognizance of a wide range of facts. I cannot do better here than to have recourse to the excellent analysis of Gilbert:

"All the processes of erosion are affected directly by the rainfall and by its distribution through the year. All are accelerated by its increase

and retarded by its diminution. When it is concentrated in one part of the year at the expense of the remainder, transportation and corrasion are accelerated and weathering retarded. Weathering is favored by abundance of moisture. Frost accomplishes most when the rocks are saturated; and solution when there is the freest circulation. But when the annual rainfall is concentrated into a limited season, a larger share of the water fails to penetrate, and the gain from temporary flooding does not compensate for the checking of all solution by a long dry season.

"Transportation is favored by increasing water supply as greatly as by increasing declivity. When the volume of a stream increases it becomes at the same time more rapid, and its transporting capacity gains by the increment to velocity as well as by the increment to volume. Hence the increase in power of transportation is more than proportional to the increase of volume. It is due to this fact chiefly that the transportation of a stream which is subject to floods is greater than it would be if its total water supply were evenly distributed in time.

"The indirect influence of rainfall and temperature by means of vegetation has different laws. Vegetation is intimately related to water supply. There is little or none where the annual precipitation is small, and it is profuse where the latter is great—especially when the temperature is at the same time high. In proportion as vegetation is profuse the solvent power of percolating water is increased, and on the other hand the ground is sheltered from the mechanical action of rains and rills. The removal of disintegrated rock is greatly impeded by the conservative power of roots and fallen leaves, and a soil is thus preserved. Transportation is retarded. Weathering by solution is accelerated up to a certain point, but in the end it suffers by the clogging of transportation. The work of frost is nearly stopped as soon as the depth of soil exceeds the limit of frost action The force of rain drops is expended on foliage. Moreover, a deep soil acts as a distributing reservoir for the water of rains and tends to equalize the flow of streams. Hence the general effect of vegetation is to retard erosion; and since the direct effect of great rainfall is the acceleration of erosion it results that its direct and indirect tendencies are in opposite directions.

"In arid regions of which the declivities are sufficient to give thorough

drainage, the absence of vegetation is accompanied by absence of soil. When a shower falls, nearly all the water runs off from the bare rock, and the little that is absorbed is rapidly reduced by evaporation. Solution becomes a slow process for lack of a continuous supply of water, and frost accomplishes its work only when it closely follows the infrequent rain. Thus weathering is retarded. Transportation has its work concentrated by the quick gathering of showers into floods so as to compensate, in part at least, for the smallness of the total rainfall from which they derive their power." (Geology of the Henry Mountains: G. K. Gilbert.)

In this analysis of Mr. Gilbert I fully concur. It remains only to apply the principles he has developed. The effects which he deduces from an arid climate *in a high country* are a scanty soil, a diminished rate of weathering, and a great efficiency of transportation. We must further consider the effects of these varied conditions upon a country composed of horizontal strata which are vertically heterogeneous. The paucity of soil lays bare the edges of the rocks. The gentler slopes or taluses being found in the softer beds these are more readily weathered than they would be if the soil were more abundant. But harder beds are not so easily dissolved, and can be broken down only by the undermining resulting from the waste of underlying softer beds. Hence the hard strata form vertical ledges, while the softer beds form taluses or steep slopes, partially protected by débris and soil. In a word, the effect of an arid climate upon such a region as the Plateau Country is to increase the amount of bare rock, to sharpen the profiles and make them irregular, and to generate cliffs. To enforce this idea, let us imagine a moist climate returning to this region. The rate of weathering in the harder beds would be accelerated and the fragments and finer material would increase the amount of soil lying upon the sloped edges of the softer beds and the weathering of the latter would be retarded. Vegetation would start into life and conserve this soil by clogging transportation, and the profiles would gradually lose their abrupt angular character and become softened and rounded, like those of the Appalachians.

If the Plateau Country were at a much lower altitude the case would be very different. Transportation would then fail for want of declivity and soil would accumulate because it could not be carried away. This, I con-

ceive, is the state of affairs in the Sahara and Arabian deserts. Vast expanses of drifting sand are formed which can be carried away only by the winds. In those deserts there are no rivers whatever, and transportation by streams is, therefore, at absolute zero. In the Plateau Country the streams, though few and mostly spasmodic, are still sufficient to lay bare an unusual amount of rock-surface. And the country is also so high that even many of the spasmodic streams can corrade deeply.

We have also mentioned in preceding chapters that another effect of an arid climate is to suppress the smaller streams, and to leave only a few of the most powerful ones which head in the highlands around the borders of the Colorado drainage basin. The intervals between these persistent streams are not corraded, but remain as flat surfaces These flat surfaces may be regarded as so many local base-levels maintaining a considerable amount of soil which protects them from erosion. The only way in which erosion can prosecute its attack at present is by sapping the faces of the walls laid bare by the few streams which are still able to corrade. The total process of erosion, therefore, resolves itself into the method which Powell has so aptly called the Recession of Cliffs. The study of some of the more striking details of this process will be one of the themes of the following chapter; and it is full of beauty and interest.

CHAPTER XIV.

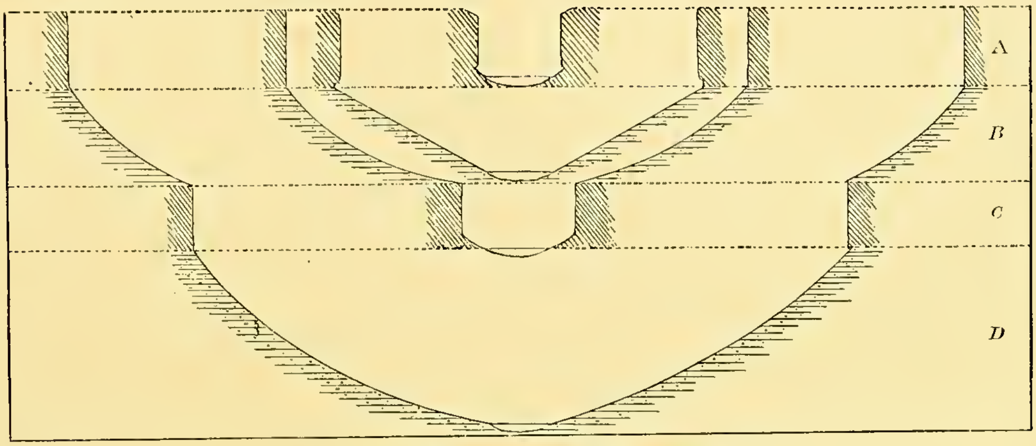
DETAILS OF EROSION.

The formation and functions of the talus.—Effect of vertical heterogeneity upon cliff profiles.—The talus acts as a protecting mantle to the softer strata.—It is the regulator of the profile.—Curvature of profiles.—Its cause.—Application of analysis to the cliffs of the Grand Cañon.—The upper Aubrey.—The cross-bedded sandstone.—The curved profile of the lower Aubrey.—Stability of normal profiles.—The Red Wall cliff.—Differences between the profiles of the Kaibab and those of the other divisions.—Explanation of the differences.—The contours or ground plans of amphitheaters and alcoves.—Rounded inward curves and projecting cusps.—Explanation of these features.—Statement of the general conditions to which the peculiar sculpture of the chasm is due.

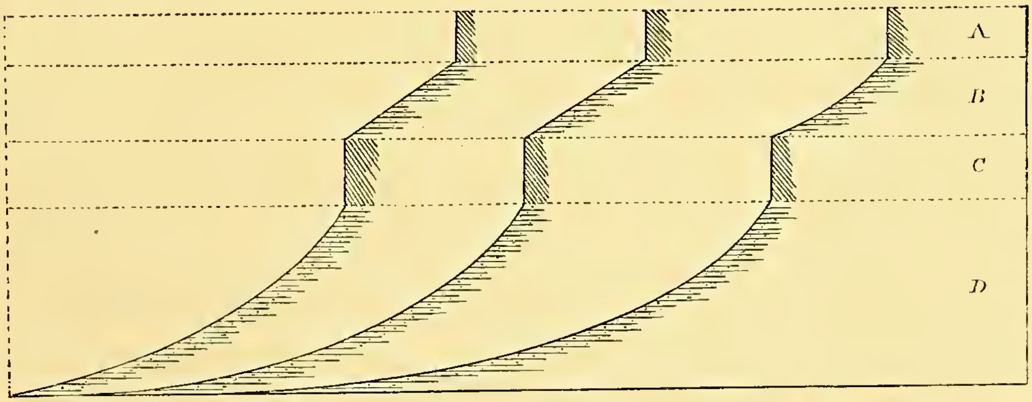
In the latter part of the preceding chapter I have formulated the more general conditions under which erosion acts. In the present chapter I shall consider the methods of operation of the forces which have produced the architectural forms displayed in the cliffs of the great chasm and of the adjoining country. The key to the problems they present is found when we analyze

THE FORMATION AND FUNCTIONS OF THE TALUS.

Since the attack of erosion under the conditions prevailing in the Plateau Country is mainly directed against the edges of the horizontal strata, and since these strata vary among themselves in respect to hardness or durability, it follows that the different beds would, if the exposures were equal, weather at different rates. The softer beds would disintegrate rapidly and undermine the edges of harder beds overlying them. The harder beds being robbed of support, cleave off by the joints and the fragments fall. The fragmental material thus produced is not immediately carried away, but remains in part and forms a talus. This talus, however, is ultimately dissipated by solution, disintegration, and transportation, and the rate at which it is finally carried off is in the long run sensibly equal to the rate at which its material is supplied. It remains to consider the arrangement



Development of Cañon Profiles.



Development of Profiles by Recession.—Upper and Lower Aubrey

DEVELOPMENT OF CLIFF PROFILES.

which this fragmental matter takes and its reaction upon the rate and mode of weathering. We may reach the matter most easily by discussing a hypothetical arbitrary case.

Let us suppose a series of strata consisting of four groups (Plate XL), the uppermost group (A) being obdurate or very unyielding to the attack of weathering; the next below (B) being notably softer or less obdurate; the third (C) being hard; and the fourth (D) soft.* Conceive a stream corrading a gash nearly but not quite through the hard upper stratum. The quantity of fragmental material furnished will vary (*ceteris paribus*) inversely with the hardness of the rock, and since the hardness is assumed to be great, the quantity supplied will be small. On the other hand, the fragments falling into the stream are quickly dissipated by corrasion. In other words, the removal of débris by transportation is for a time at the extreme of rapidity. Corrasion, moreover, while a country is rising, is a very rapid process in comparison with the rate of recession of a hard massive wall. Very little talus, therefore, can form at this stage; the obduracy of the wall rock prevents its recession; little material is supplied which could serve to form a talus, and that little is quickly swept off by the stream. Hence the cañon will be narrow, with vertical or nearly vertical walls, and no appreciable talus will accumulate.

Conceive now the corrasion to go on until the stream has cut nearly but not quite through the soft group B. The supply of débris is greatly increased. The soft beds weather easily and undermine the hard beds above. Let us recall here that the width of the cut is no greater than the width of the water surface. As the cliff recedes the fragments begin to find a lodgment at its base, and though some of them roll into the stream and are devoured, yet another portion must await the slower process of solution and gradual decay before disappearing. Thus the rate of transportation slackens by the decreasing declivity of the river, while the rate of supply of débris increases. As the cliff further recedes the talus mounts higher and higher up the breast of the softer part of the wall. The faces of the softer strata become in due time a slope capable of supporting a talus.

*I am unable to think of a pair of adjectives which will suitably express the great and small degrees of obduracy of rocks against weathering. I shall use the terms "hard" and "soft," therefore, in this sense.

Conceive now the stream cutting nearly but not quite through the second hard group C. The case here is not quite the same as when it was cut near to the base of A; for in the earlier or higher stage of the river all the débris came from A alone; while in the present case A, B, and C are all furnishing fragmental matter. Hence the corrasion is slackened and a small amount of talus may accumulate at the edge of the stream. Still the edges of C will be nearly vertical except very near the bottom.

Finally, conceive the stream to have cut through the soft group D, and suppose that at the bottom of this group it remains for a considerable period at a base-level The edges of D are steadily sapped and C is undermined. But the undermining of C cuts off the foot of the slope in B, increasing the declivity in that group and facilitating the descent of fragments. And this, in turn, accelerates the rate of weathering in B and the rate of undermining of A. Thus, curiously enough, the state of affairs at the bottom of the cañon influences the rate of recession at the summit of its wall.

We must now note the fact that a talus acts as a protecting mantle to the rocks it covers, screening them partially from dissolution by weathering. The heavier the talus the greater is the protection. But the amount of talus which can remain at any given level is dependent inversely upon the slope; and the talus is always descending by the action of the rains. Hence the accumulation is greatest at the bottom of the cañon. When, therefore, the recession of the wall has gone so far that the descending fragments do not fall at once into the stream, the lowest beds of all receive the most protection. The rate of recession of these lowest beds, therefore, becomes retarded. The protection diminishes as we go higher and the rate of recession increases correspondingly.

It follows at once that the talus is the regulator of the cliff-profile; for it checks the rate of recession in the softer beds, keeping their recession *down* to the mean rate, while, by undermining, the recession of the hard beds is brought *up* to the mean rate. As soon as the talus is established on the lowest slope (D), the cliff may be said to have attained its normal profile, and in all subsequent recession that profile undergoes little change. The only modification it receives is a decrease in the slope D, which becomes longer and also takes the form of a curve, concave upwards. The

cause of this curvature is as follows. If the rate of recession in the soft beds, as due to the protection of talus, were proportional in a simple ratio to the height above the bottom, the slope would be straight, but would gradually decrease its inclination as the cliff recedes. But, in fact, the law governing the rate of recession is more complex. The protection given to the lower beds increases downwards in a higher ratio than a simple one, being as the square of the distance below the base of C, or, perhaps, in a still higher ratio This arises from the fact that not only is the quantity of débris and soil greater in the lowest beds, but it is finer and more compact. Hence the rate of recession becomes inversely proportional to the square (?) of the distance below the base of C, and the curve becomes a segment of an hyperbola.

The conclusions from the foregoing discussion are abundantly exemplified throughout the cliffs and cañons of the Plateau Country. Take, for instance, the case of the Jurassic sandstone as one extreme. This rock is very hard and resistant and very homogeneous. It weathers with extreme slowness. The cañons which are cut deeply into it, but not through it or deeply into the Trias below, are always narrow and have very bold and precipitous walls. The extreme is reached in the cañons of the forks of the Virgen. These are merely narrow clefts in the rocks many hundreds of feet in depth. But as soon as the stream beds cut into the softer members of the middle and lower Trias the chasms at once widen out and then grow wider as the stream cuts lower. The talus at the base of the Jurassic escarpments is always small and often entirely absent. It is, moreover, a general fact that the cañons narrow up as they pass into hard rocks and widen out as they pass into soft rocks.

In the foregoing discussion we have all the conditions necessary for understanding the cliff-work and sculpture of the Grand Cañon, and we may now proceed to apply these principles to the peculiar profiles which the chasm presents in its several portions. The summit beds, consisting of arenaceous and cherty limestones, are of medium obduracy. They contain a large amount of silicious matter, and if blocks of it were submitted to the stone-cutter they would be pronounced excessively tough and hard; but, owing to the presence of an abundant calcareous cement of soluble char-

acter, it yields readily to weathering. Much of the silica has been aggregated into the form of cherty nodules, which are very abundant, forming, indeed, a considerable percentage of the entire mass of these beds. The nodules are to a considerable extent arranged in horizontal bands, occurring at frequent intervals, with separating layers of sandy limestone, in which the nodules, though still numerous, are less frequent. In the process of weathering, the nodules are less easily dissolved than the inclosing matrix, and as the rock decays they are left projecting from its mass, giving the faces at a little distance the appearance of a bedded conglomerate. Ultimately they are detached and fall down upon the talus below. Millions of these nodules are found in the great talus across the edges of the lower Aubrey.

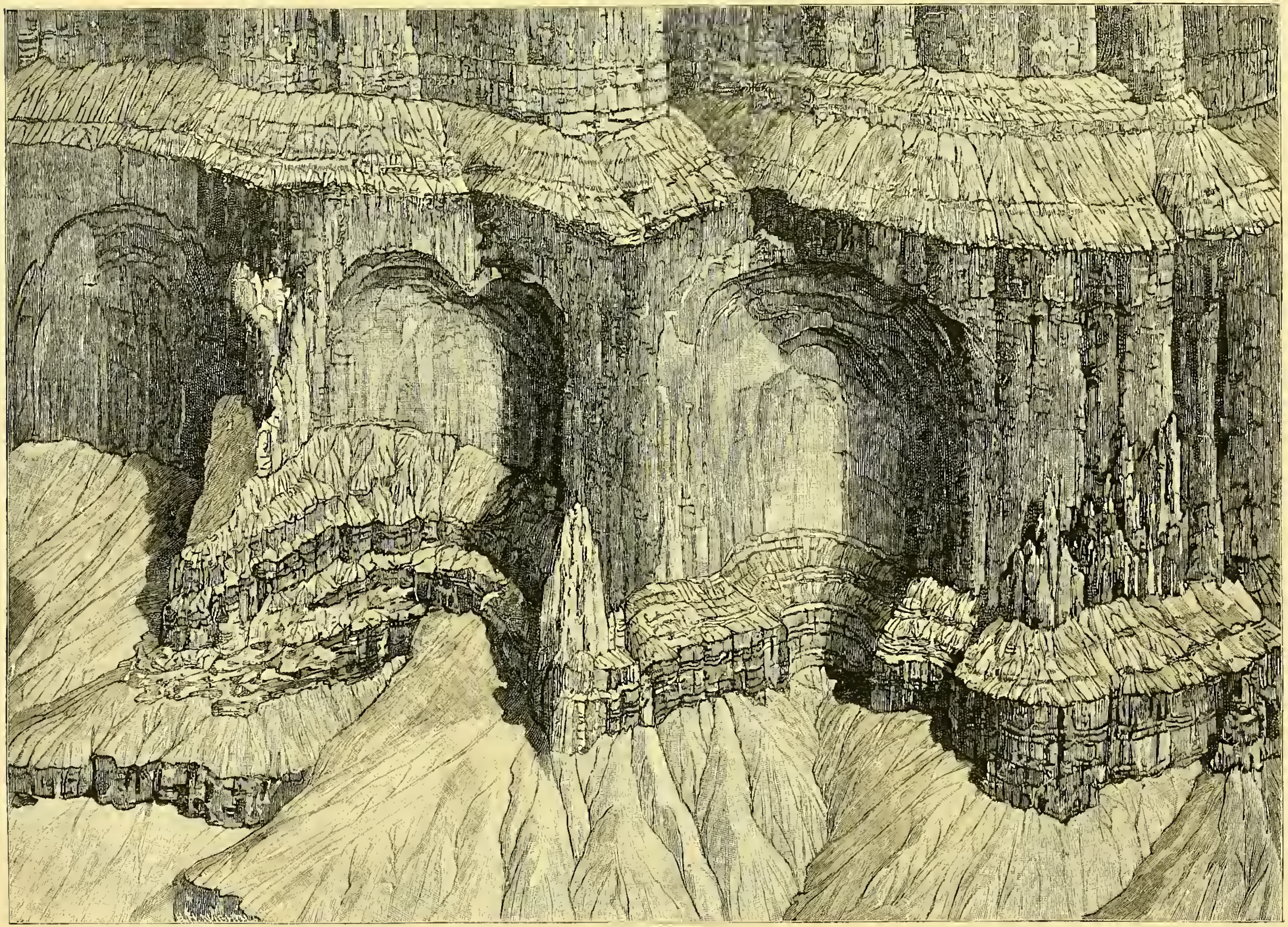
The thickness of the upper Aubrey limestones (of which there are several members of somewhat varied constitution) is altogether about 700 feet. Beneath them comes the hardest and most obdurate mass of the entire Carboniferous series—the cross-bedded sandstone. Its thickness is about 350 to 375 feet. It forms a vertical ledge which is seldom broken into a slope. It is seen as a most conspicuous band in the summit wall in every amphitheater and promontory. Beneath it is a vass mass of rather thinly bedded sandstones, constituting the lower Aubrey group. Their total thickness exceeds a thousand feet. These sandstones are the most yielding of any portion of the Carboniferous series, since the cement which holds the mass together is to a notable extent gypsiferous. It seldom forms a great cliff, but is in reality a succession of ledges often imperfect and beveled off, but sometimes well marked and precipitous. The individual ledges are of very small altitude, corresponding to the thickness of the several members. They are to a considerable degree protected by the nodules of chert and the slabs of hard sandstone shot down from the calcareous members and cross-bedded sandstone above. In the vast expanse of wall surface the individuality of the separate ledges disappears, and the general effect conveyed by the lower Aubrey is that of a long, steep, and regular slope. When seen in profile the true slope is readily appreciated; but when viewed directly in front, or with moderate obliquity, it looks too steep for human foothold, though it is by no means so.

Leaving for future consideration the characteristics of the great Red Wall group and the strata beneath it, let us endeavor to infer the typical forms of cliff profiles generated by the combined action of corrasion and weathering in the strata thus far described. Imagine first a stream corrading its channel through the upper Aubrey limestones. The degree of abruptness in the slopes descending to the stream would be dependent upon the rate of weathering relatively to the rate of corrasion. If the rate of corrasion were slow and the rate of weathering rapid the slopes would be gentle or at a low angle; if the corrasion were rapid and the weathering slow the banks would be precipitous. Imagine the stream to corrade still further into and through the very obdurate cross-bedded sandstone. Upon this latter rock weathering has but little effect directly. It may stand for long geological periods with but a slight loss of substance, provided it is not undermined. Corrasion, however, may go on in it at a rate somewhat retarded by its obduracy indeed, but only a little less rapidly than in much softer rocks; for declivity and the amount of protection afforded by the clastic material in the bed of a stream are incomparably more potent factors than the hardness of the bed-rock in determining the rate of corrasion. But the rate of weathering is dependent upon the nature of the stratum itself. Hence the limestones above would be much less precipitous than the adamantine sandstone below.

Imagine, further, the sinking of the channel deep into the very easily weathered shaly sandstones of the lower Aubrey. The problem now becomes a little more complicated. As before, the quality of the newly-cut rocks does not necessarily imply any great increase in the rate of corrasion. But it does imply a modification in the rate of weathering and in the consequent form of the profile. A new factor now enters in the plan of operations. In consequence of their very yielding character the shaly sandstones are rapidly dissolved and the adamantine stratum above is *undermined.* The rate of recession becomes in the harder stratum equal to that in the softer shales beneath it. So rapid at first is this decay that at a certain early stage of the penetration of shales by the corrading stream the cross-bedded sandstone and the cherty limestones above often form a single ledge. The rate at which they are undermined is for a time greater than the rate of reces-

sion in the medium-hard cherty limestones. But this condition is gradually brought to a check by the formation of a talus. We have observed that the softer and more yielding the beds under the action of weathering the longer and less steep will be the weathered slope across their edges. Upon this slope across the edges of the shaly sandstones accumulate many of the cherty nodules and fragments of the adamantine sandstone, with large quantities of fine sand, and even a little soil. The débris lodging there protects, to an important extent, the shaly sandstones and retards more and more their rate of weathering, retards the rate of undermining, and diminishes gradually the supply of débris to the talus. Thus the great increase in the rate of weathering caused by corrasion penetrating the yielding shales is, to a great extent, countervailed by the formation of the talus. It now becomes apparent that the resulting profile of the entire cliff has a perfectly definite and stable configuration or typical form, which the combined action of all the incident forces tends strongly to maintain.

The cliff formed out of the upper and lower Aubrey series is very remarkable for the constancy of its profile throughout the entire extent of the great chasm. Along every mile of the main façade, in every amphitheater and alcove, and in every promontory, wing wall, and gable, it discloses the same familiar features. It is the wall of the upper or outer chasm. In the Kanab, Uinkaret, and Sheavwits divisions it stands far away from the lower or inner chasm—an interval of two miles usually separating its base from the brink of the inner gorge. In the Kaibab division the Aubrey wall is unchanged in its general character, but everything below it is there in strong contrast with what is disclosed in the other divisions. In the three western divisions the broad platform at the base of the upper wall is a very striking feature; in the Kaibab the platform is quarried away by the lower depths of the amphitheaters, leaving only intervening buttes, and the profile at the base of the great lower Aubrey talus at once plunges vertically down the precipices of the Red Wall limestone. In many places the Aubrey cliff in its recession by waste is so closely pursued by the recession of the Red Wall below that a few hundred feet of the lower Aubrey talus are cut off and the shales at the base of that series are undermined, forming cliffs which are continuous vertically with the great Red Wall precipice below. Almost



NICHES OR PANELS IN THE RED WALL LIMESTONE.

The panels are over 600 feet high.

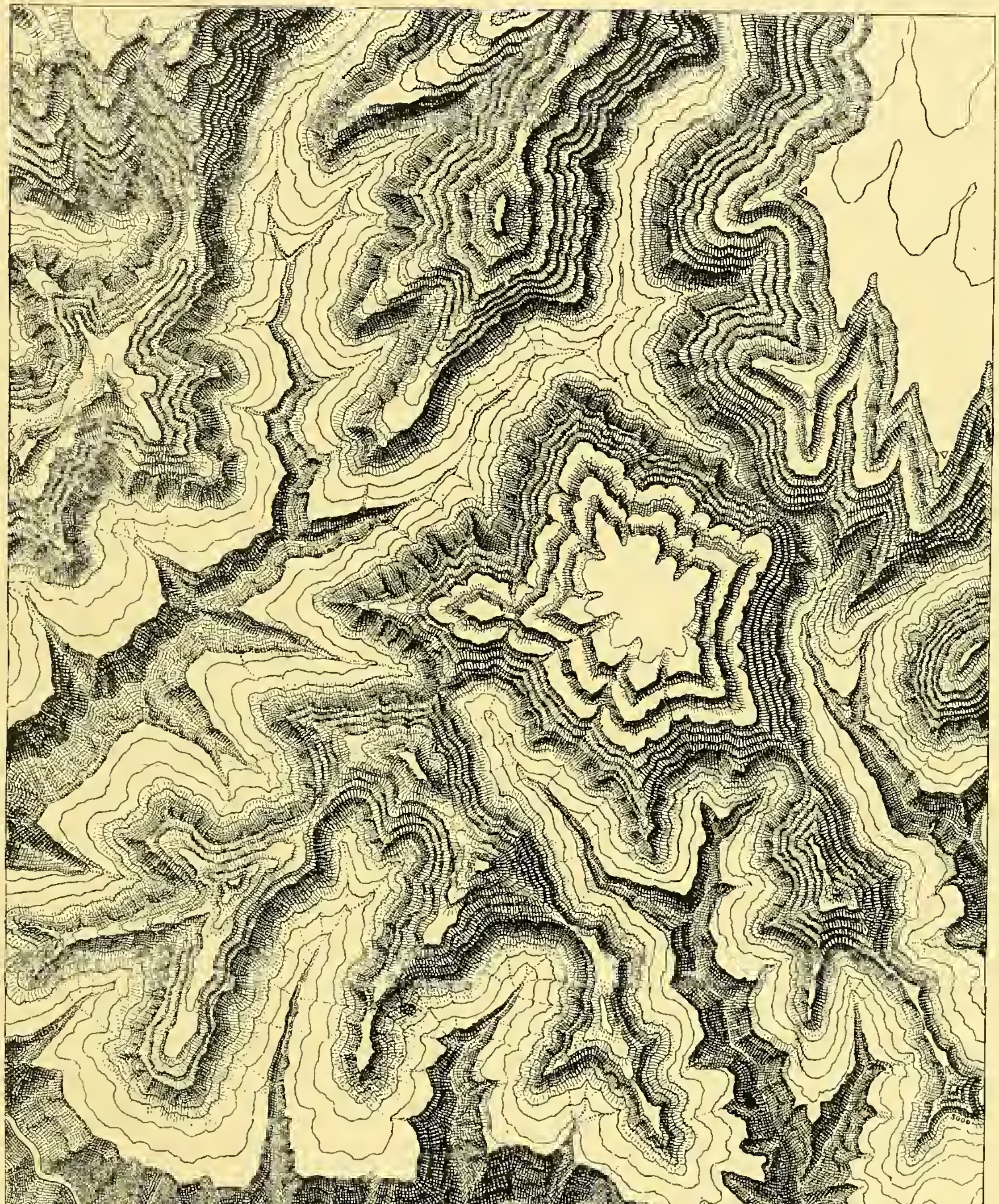
everywhere, in fact, throughout the Kaibab division the platform of the Middle Terrace is obliterated and the entire Carboniferous series forms one wall of alternate vertical ledges and taluses. The reason for this difference will soon become manifest.

Let us now pursue further the evolution of the cliffs by imagining the sinking of a stream by corrasion into the Red Wall series. This formation, constituting the lower Carboniferous of the southwestern Plateau Country, is one of the most extraordinary in the world. It is composed principally of limestones of the most massive and homogeneous description, one bed being over 750 feet in thickness without any visible horizontal parting; another of nearly 400 feet, and a third of more than 300 feet. There are also several other massive layers of limestone, and these calcareous beds are quite similar to each other in their lithological characters. At the summit of the Red Wall is a group of calcareous sandstones, very heavily bedded for the most part, and about 350 feet in total thickness. Beneath the huge limestone members other calcareous sandstones appear in considerable mass, with a thickness of about 750 feet. These lower beds are conspicuous to the eye by their deep rich brown color. With the exception of the largest limestone member, all of these great beds vary somewhat as they pass through great horizontal distances. They often subdivide into thinner beds and the amount of arenaceous matter which they contain also changes. These changes of character, however, are seldom or never abrupt, but usually take place by almost imperceptible degrees along many miles of exposure. In the Kanab division the whole series of nearly 2,500 feet thickness is wonderfully massive, and the partings of the strata are comparatively few. In the Kaibab the great 750-foot limestone is as solid as ever, but most of the other members have become laminated much more minutely than in the Kanab and Uinkaret, and are of more perishable texture. The results of the attack of weathering upon the edges exposed by corrasion vary accordingly. In the Kaibab several causes have combined to produce a far greater amount of destruction in the Red Wall series than in the Kanab and Uinkaret divisions.

The causes which have produced in the Kaibab a topography differing so widely from that which is seen in the other divisions of the chasm may be

readily explained. The Kaibab is now, and throughout the period of evolution of the chasm it always has been, higher than the other plateaus. Corrasion has, therefore, penetrated there more deeply than elsewhere. It has, moreover, laid bare the edges of the softer beds underlying the Red Wall, and the rapid decay of these lower beds has undermined and wasted the Red Wall to a great extent In the other divisions of the chasm corrasion has only at a very recent period cut below this great series of hard limestones. In a word, the process of development of the cañon is much more advanced than elsewhere. Besides the greater altitude leading to deeper corrasion, the climate of the Kaibab is moister, and the degrading forces are, therefore, more efficient. If, in future periods, the three western plateaus should be further elevated, it may be anticipated that the chasm would there assume gradually the features now seen in the Kaibab.

There are certain forms in the contours or ground plans of cliffs which claim attention. One of the most striking features in the vast maze of cliff-work in the Grand Cañon is found in the extremely tortuous lines of frontage. They wind about in a most intricate manner and rarely extend in straight lines through any considerable distances. The lines of trend usually are a succession of sweeping curves and sharp angles. The first view is extremely confusing, and under the influence of many causes of optical delusion prevailing in the landscape, it is very difficult to see anything but chaos—an utter absence of anything like system or arrangement. But patient study and analysis at length reveal many striking evidences of order. If we consider any one of the larger amphitheaters opening laterally into the main chasm, we shall note that it has many lateral amphitheaters opening into it of an inferior order of magnitude. This is well portrayed in Mr. Bodfish's map of the Kaibab division. All of them are the result of corrasion and weathering. They illustrate the remarkable uniformity of the rate of weathering. The upper ends of the minor recesses are usually rounded in contour. The longitudinal wall extending to its confluence with the main amphitheater makes at that point a sharp angle. The weathering of these walls has obviously originated in the corrading channels of the lateral tributaries and their minuter branches. As the narrow cleft cut by the sinking stream deepened it also widened. If we rep-



ROUNDED INWARD CURVES AND PROJECTI[illegible] CUSPS OF THE WALLS.

resent the locus of the edge of any stratum high in the series at successive epochs of the development by parallel equidistant lines, we shall have a series of curves running up the stream nearly parallel to its course, then circling around its head and returning to its mouth. As these curves recede from the stream the more nearly do they approach to arcs of circles. The same recession is going on in the walls of the main amphitheater, into which the minor one opens. Where two minor or major amphitheaters are situated near each other the recession of their walls at length obliterates a portion of the summit stratum which divided them, and at later stages successively obliterates lower and lower members. The great cloister-buttes are formed by the recession of the walls of any two parallel major amphitheaters, and the wings of these buttes by the recession of the walls of the minor amphitheaters. The minor recesses exhibit the rounded contours at their upper ends. Everywhere is disclosed an approximate uniformity in the rate of recession. Where the expanding curves of recession from any two adjoining recesses meet or intersect, the included mass between them is carved sometimes into a cusp or sharp "spur," sometimes into a stately gable, according to the relative positions of the axes of the curves. The spurs are frequently very narrow and sharp, and in an advanced state of erosion such a spur in the Red Wall band breaks into a row of needles or pinnacles. Many of the gables are of most noble form and of wonderful symmetry. Human conception cannot surpass their beauty even if it can rival it.

The cusp contour is also repeated on a minor scale in the wall faces, where it appears as a minor decoration or fretting of the edges of the strata. It is especially conspicuous in the Kaibab. It appears to have its origin in minor corrasion by storm sluices, which at first scour out at frequent and regular intervals deep notches, which widen out by weathering, and once started the recesses or alcoves thus opened perpetuate themselves. The contour line along the face of the cliff thus curves inward and the intersection of two curves at their ends forms the cusp.

In the faces of the great limestone member of the Red Wall may be seen large niches or panels of very regular form spanned by circular arches above. These panels must be more than 600 feet high and 500 to 600 feet wide. Sometimes they are very deeply recessed in the façade, sometimes

only slightly so. There are literally hundreds of these niches along the extent of the limestone front, and, so far as known, they are seen in no other member. Mr. Holmes has made a drawing of three of these (Plate XLI), which well represents their character. I am unable to explain the cause of this persistent phenomenon and am very much perplexed by it. There is seldom any long stretch of the Red Wall exposure in which these panels are not found, and they are usually of the same form and dimensions throughout the Kaibab division. In the Kanab and Uinkaret divisions they are much less numerous, though still common.

The analysis of details in the sculpture of the Grand Cañon might be extended almost without limit, but the examples here given must suffice. It appears that the laws which govern the action of the eroding agents are highly complex, though by careful study and close attention they may be mastered. As already remarked these peculiar forms would hardly be possible in any other region, since no other region (so far as known to me) presents similar conditions. These conditions have been stated to be as follows, and the effect of each has been stated: (1.) The great elevation of the region. (2.) The horizontality of the strata. (3.) A series of strata containing very massive beds, which differ greatly among themselves in respect to obduracy to weathering, but each member being very homogeneous in all its horizontal extent; in a word, heterogeneity in vertical range and homogeneity in horizontal range. (4.) An arid climate.

No doubt the question will often be asked, how long has been the time occupied in the excavation of the Grand Cañon? Unfortunately there is no mystery more inscrutable than the duration of geological time. On this point geologists have obtained no satisfactory results in any part of the world. Whatever periods may have been assigned to the antiquity of past events have been assigned provisionally only, and the inferences are almost purely hypothetical. In the Plateau Country Nature has, in some respects, been more communicative than in other regions, and has answered many questions far more fully and graciously. But here, as elsewhere, whenever we interrogate her about time other than relative, her lips are sternly closed, and her face becomes as the face of the Sphinx.

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